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HOW TO USE YOUR VOM VTVM & OSCILLOSCOPE

BY MARTIN CLIFFORD

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How to Use Your VOM VTVM & OSCILLOSCOPE

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Mike Bosnich
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BY MARTIN CLIFFORD

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CAUTION

BE SURE THAT THE RED WIRE INSIDE THIS METER MUST BE CUT BEFORE THE BATTERY IS INSERTED

Preface

In the field of electronics there is a confusing variety of test and measuring equipment, each unit designed for a specific purpose. However, the majority of equipment tests can be performed with the three insturments discussed in this book. Regardless of your interest in electronics—technician, ham, experimenter, hobbyist—the information in these pages provides a handy reference guide to the use and function of these instruments.

While there has been much information published on such equipment, this book is intended to serve as a basic volume on all three units, eliminating the necessity of going from one book to another for the needed information.

The material is arranged in three parts, each devoted entirely to a single instrument. Part I deals with the volt-ohm-milliameter, more frequently called a VOM or multitester. With the information given, an individual with only a meager understanding of electronics can learn to make tests and how to read various meter scales. Part II tells how a VTVM works and how to use it. Part III completely describes the oscilloscope and its applications.

If you are a hobbyist or experimenter, the first chapter of each part will be of vital interest; each instrument is described in detail, including extensive how-it-works information and illustrations. (Even old pros might find these chapters refreshing!) The second chapter in each part is devoted to the use of each unit, suggesting basic as well as unique applications in various phases of electronics. For trouble-shooting techniques, the third chapter in each part deals with

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servicing, including troubleshooting charts that list the more common causes of equipment malfunction and failure.

Whether your interest is in professional servicing and maintenance, amateur radio, or if electronics is simply your hobby, this book will serve as a handy reference guide.

Martin Clifford

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PART I

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CHAPTER 1

How a VOM Works

Of all the electronic test instruments used by technicians, engineers, and others who work with electronic equipment, The volt-ohm-milliammeter is probably the most common. There is good reason for this. The instrument—commonly referred to as a multimeter, multitester, volt-ohmmeter, or just plain VOM—can be used to measure a wide range of resistances, voltages, and currents. VOMs are battery powered, and therefore are readily portable since they are free from both a line cord and a power outlet. VOMs are generally inexpensive and can be purchased in kit form or as complete units. Some VOMs are extremely sensitive, with input impedance ratings of up to 100,000 ohms-per-volt. The instrument is sturdy and reliable, and it can be used for servicing any kind of electronic and electrical equipment.

Having a VOM is one thing—being able to use it properly is another. The VOM is so simple that even inexperienced persons often are able to make some measurements with it, but in the hands of someone who is familiar with the instrument, it can be made to reveal an astonishing amount of information. This Chapter explains in simple terns how the VOM works. Once you can read the scales and know how to use the instrument, you will be able to go far beyond the suggestions contained in this book.

Meter Movement

The heart of every VOM is a current-sensitive device known as a d'Arsonval movement (also called a moving-coil meter or a galvanometer). This type of meter movement is an electromagnetic device which serves as the basic indicator for all measurements. The basic structure of the d'Arsonval meter is shown in Fig. 1-1. A coil of wire, wound on an iron core,

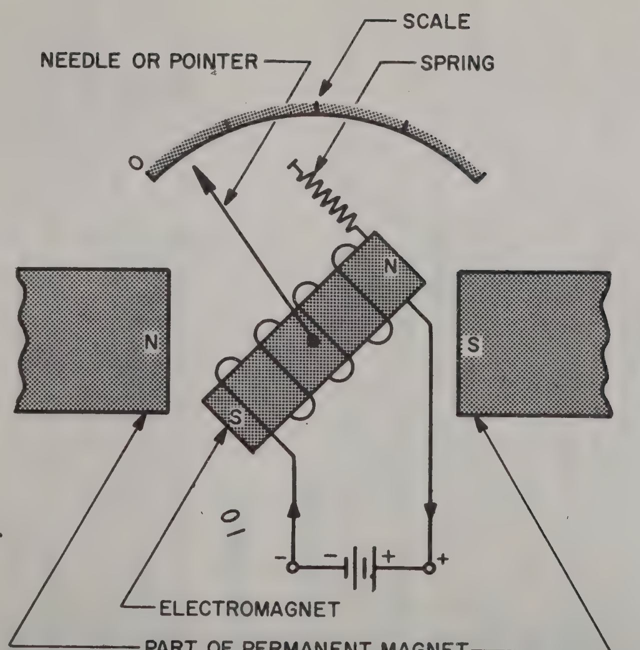


Fig. 1-1. Basic structure of a d'Arsonval meter. Notice the direction of current flow through the coil.

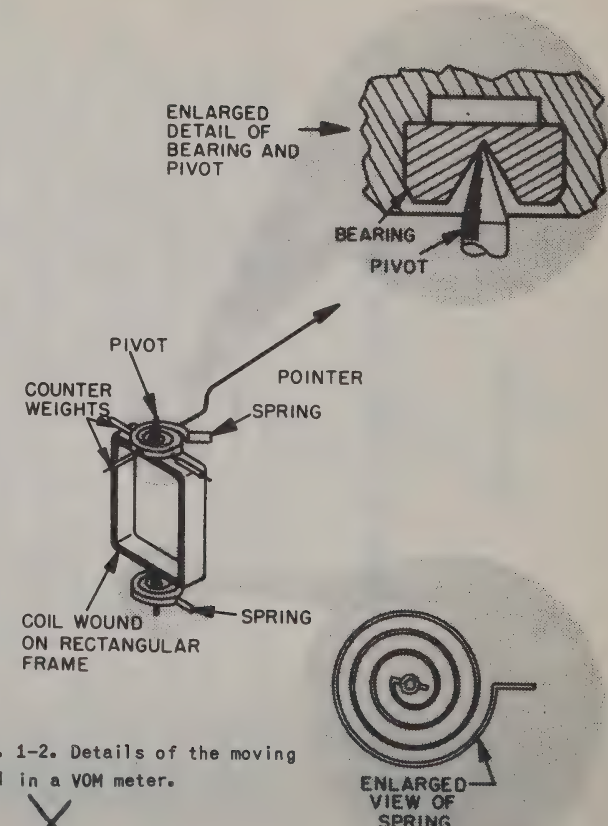


Fig. 1-2. Details of the moving coil in a VOM meter.

is mounted between the poles of a permanent magnet. This coil is pivoted so it is free to rotate. Mounted on the coil is a meter needle or pointer which turns with the coil. A spring fastened to one end of the coil holds it in place, keeping it from spinning on its pivot. A scale is placed beneath the arrowhead of the pointer, which is normally positioned at the zero mark on the left-hand end of the scale when the instrument is not in use.

When direct current (DC) flows through the coil it becomes an electromagnet. The force between the poles of the electromagnet and of the permanent magnet is strong enough to overcome the restraining action of the spring, producing some rotation of the coil. The amount of coil movement depends on the number of turns in the coil, the amount of current flowing through it, and the type of core. As you can see, the d'Arsonval meter is a current-operated device. Its action depends on an electrical current flowing through the coil. However, the scale beneath the pointer is marked not only in terms of current, but in resistance and voltage as well. Although the basic meter is a DC instrument, requiring a direct current input, it can be used to measure alternating current and voltage (AC) by using a rectifier circuit input.

The coil itself is wound on a light-weight, rectangular aluminum frame know as a "bobbin." The greater the number of turns the coil has, the more sensitive it will be to small currents. But the more turns of wire the moving coil has, the greater will be its resistance. That is why extremely sensitive meters have a high internal resistance. Mounted on the bobbin with the coil are a pair of springs and two pivots. The springs serve a double purpose. They bring the meter pointer back to zero when no current is flowing through the coil, and they provide the electrical connections to the coil. Pivots mounted in bearings at the top and bottom of the coil (Fig. 1-2) enable the coil to rotate. Of course, there is a certain amount of friction here, but the greater the coil resistance (the more turns it has) the more responsive it will be to small currents.

One of the problems in the design of the VOM is that the meter must be usable in any position, vertical or horizontal. Although the meter pointer is extremely light, its weight must be counter-balanced, as shown in Fig. 1-2; otherwise, the

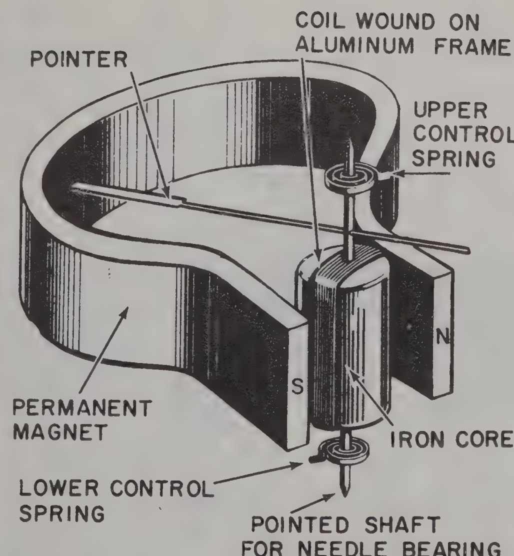
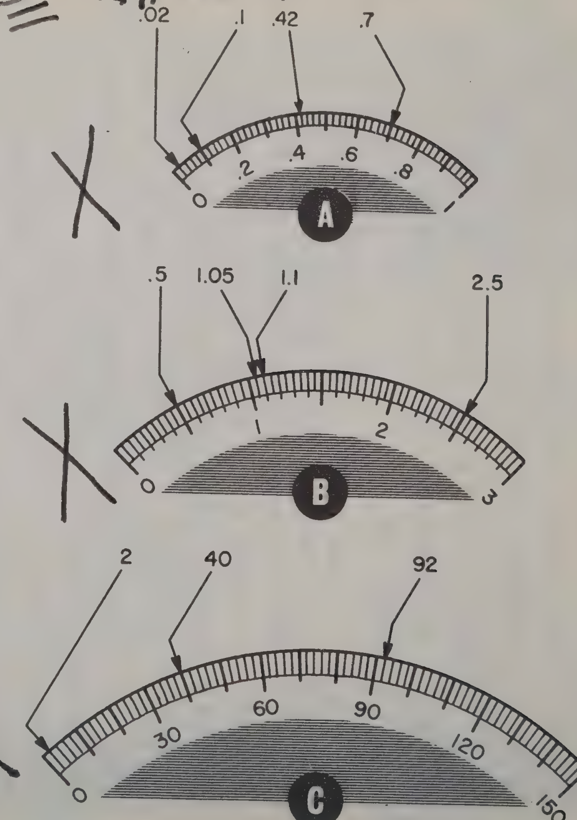


Fig. 1-3. D'Arsonval meter movement construction details.

Fig. 1-4. Typical linear scales. ►

3 ≡ LINEAR SCALES



pointer would tend to rest on the scale when the meter was placed in a horizontal position.

The greater the strength of the electromagnetic field created by the coil when it has a current flowing through it, the more sensitive the instrument will be. Thus, an iron core such as shown in Fig. 1-3 is employed. This iron core remains fixed and the coil bobbin rotates around it. For the sake of clarity the pole pieces of the permanent magnet are not shown. These are curved pieces of magnetic metal which fit around the inside of the permanent magnet, practically surrounding the bobbin or moving coil. Thus, the moving coil rotates in the magnetic field of the permanent magnet no matter what its position may be. Also omitted are the counterweights which mount on cross arms on the lower end of the pointer.

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Meter Scales

The VOM is a multipurpose instrument, designed to measure a variety of voltages and currents, both AC and DC, in addition to resistance. Thus, its scales and switching arrangements are sometimes confusing. The scales are often printed in two colors—black for DC resistance and decibel measurements, red for AC. A typical VOM may have one scale for resistance measurements, three scales for DC measurements, another three for AC measurements, and one scale for decibels. Furthermore, these scales will be of different types—linear, nonlinear, and logarithmic. As you can see, it is not only important to know which scale to read, but how to read it.

Let's start with a linear scale, since this is the easiest type to read. Fig. 1-4 shows three examples of linear scales. Notice that each of these ends with a different number and that the divisions on each of the scales is different. The first step in reading one of these scales is to take a look at the last number, which represents full-scale deflection of the meter. The full scale reading in Fig. 1-4A is 1; in Fig. 1-4B it is 3; and in the last scale it is 150.

Notice that values or numbers are assigned only to some division marks. This means it will be up to you to interpolate the value of each division in between the numbered ones. As a start, examine the first linear scale (A). This has a range from 0 at the left to 1 at the right; thus, each major division

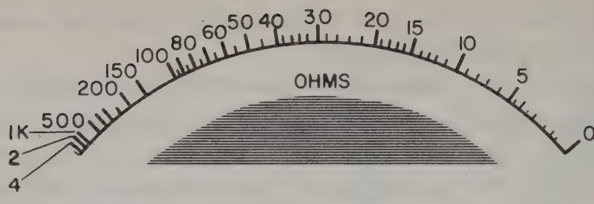

Fig. 1-5. A typical resistance scale.

has a value of 0.2, which is marked right on the scale. The unmarked major divisions, identified by heavy lines which extend slightly below the curve of the scale, each have a value of 0.1—one-tenth the full-scale value. Each of the smallest lines therefore represents a value of .02. Thus, the first line immediately following the number .2 would have a value of .22. The next would be .24, the next .26, then .28, and the heavy line would be .3.

The next linear scale (B) has a full range of 3. The center mark of this scale would then be 1.5, and each major unmarked division would represent a value of .5. Each of the smaller divisions has a value of .05, and if you add all of them you will have a total of 3 when you reach the end of the scale. The last linear scale (C) has a full scale value of 150. Each major division is 30 and is marked as such. Each line has a value of 2. Various representative values are marked on each of the scales as examples, but the best way to become experienced in scale reading is to practice.

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Range Multiplier

On most meters scale ranges are extended through the use of a multiplier switch. With the range switch set on some position, such as 10x, all readings must be multiplied by 10. If, as an example, you were using scale B in Fig. 1-4 and the needle were pointing at 2.5, you would mentally multiply by 10 and get an answer of 25. An easier way of doing this is to move the decimal point of the number 2.5 one place to the

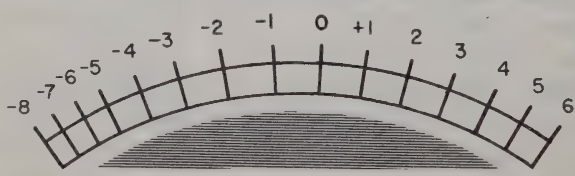

Fig. 1-6. A typical decibel scale.

right. Linear scales are used to indicate values of AC or DC voltage or current, although on many meters the lower end of the AC scale may be slightly nonlinear. ?

The Nonlinear Scale

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Fig. 1-5 shows an example of a nonlinear scale. It is nonlinear because the divisions or marking lines on the scale are not spaced evenly. Notice how crowded the scale becomes toward the left. The value of each division also becomes greater in this direction. Each large division mark between the numbers 0 and 5 has a value of 1, but there is only one division between 40 and 50, indicating a value of 45.

The technique for reading this kind of scale is entirely different than for a linear scale. If the meter pointer comes to rest between two numbers on the scale, you must read both numbers and then determine the value of each division between these numbers. Unlike a linear scale, knowing the full-scale deflection value—the number at the far right on the scale—isn't of help. And at the extreme left end of the scale, the numbers are so crowded that all you can do is make an educated guess at the reading.

The resistance scale of the VOM is usually above all the other scales and, like the other scales, may be extended by using the range multiplier control. Thus, on a typical VOM, R x 1 would indicate that the scale is to be read directly. R x 10 means each reading should be multiplied by 10. R x 100 means each reading should be multiplied by 100. Unlike the voltage scales, though, the zero end of the resistance scale is at the far right, with increasing values toward the left. As the meter pointer moves toward the left you have an indication of greater resistance. The extreme left end of the scale indicates maximum resistance or an open circuit.

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The Logarithmic Scale

Unlike the other scales, the logarithmic scale shown in Fig. 1-6 does not have its zero at either end, but somewhere near the center of the scale. The scale shown is calibrated in terms of decibels (db), helpful when making audio measurements. The scale may be marked with plus and minus signs—plus to the right of zero, minus to the left of zero.

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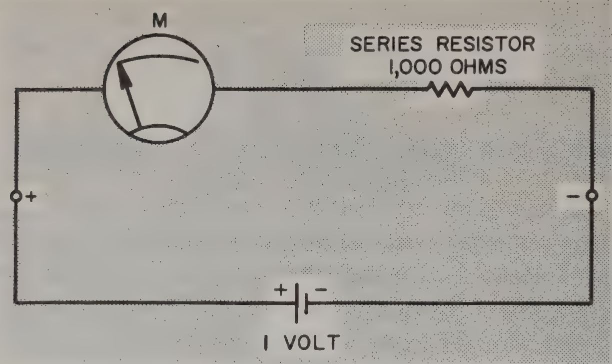

Fig. 1-7. As indicated here, a 1-volt battery and a 1,000-ohm resistor produce 1 milliampere of current through the meter (ignoring the internal resistance of the meter).

Reading the logarithmic db scale is much the same as reading the other scales. Actually, it is much easier since each division is usually (but not always) marked. As you can see, the scale becomes more crowded toward the left side. And, unlike the scales used for resistance or voltage (or current), there is no range multiplier on the VOM for the logarithmic scale.

Basic VOM Circuit

Basically, the VOM consists of the meter movement, a re-

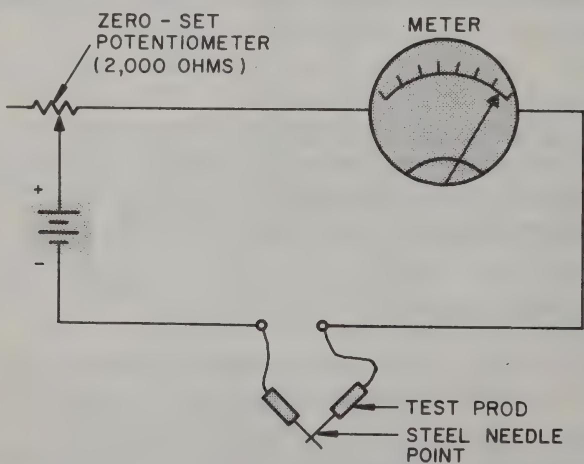

Fig. 1-8. The potentiometer in this ohmmeter circuit enables us to set the meter current exactly.

sistor, and a battery. However, the battery is used only when resistance is to be measured. When the VOM is used for measuring voltage or current, the basic circuit of the VOM becomes even simpler, consisting only of a resistor and the meter.

A basic VOM circuit is shown in Fig. 1-7. In this particular circuit the maximum current we may send through the meter is 1 milliampere (or .001 ampere). With this much direct current flowing through the meter, the pointer will swing to the far right and will come to rest at the end of the scale. Any current through the meter much greater than 1 milliampere will burn out the coil. How can we produce a current of exactly 1 milliampere? Fig. 1-7 shows that we can do it with a 1-volt battery and a resistor of 1,000 ohms (ignoring the internal resistance of the meter). The current through the resistor, however, also flows through the coil and through the resistance of the battery itself. The coil has some resistance, and so has the battery. Because this resistance is added to the 1,000-ohm current-limiting resistor, the current is actually somewhat less than 1 milliampere. To compensate for this we can make our resistor a variable unit.

A modified circuit appears in Fig. 1-8. Instead of using a 1,000-ohm fixed resistor, we have replaced it with a potentiometer having a value of 2,000 ohms. This variable resistor is called the zero-set or zero-adjust control. We use a potentiometer having a value of 2,000 ohms, since this permits us to set the control somewhere around its center position instead of working near the end of the control. There is another advantage in using a potentiometer. As the battery gets older, its resistance increases. The variable control can be adjusted to compensate for this.

Fig. 1-8 also shows a pair of test probes. These have the double function of serving as a switch and also for probing or testing a circuit. When the metal ends of the probes do not touch, the circuit is open. Current does not flow through the meter and the meter pointer rests on the first division or mark at the left side of the scales. But if we touch the probe points together, it will be as though we had closed a switch. Current will flow through the circuit from the negative terminal of the battery, through the wire leads of the probes, through the meter coil (causing it to move), through the potentiometer, and back through the battery to the negative terminal again.

What will be the position of the meter pointer at this time? It should be over at the far right of the meter scale, resting on the last or final division mark. This tells us that we have 1 milliampere of current flowing in the circuit; hence, we see that the meter is really a current-measuring device. But how do we know that the meter pointer will stop exactly at the last division of the meter scale? We don't. This is where the zero-set control goes to work. All that is necessary is to adjust it so the pointer stops where we want it to. The potentiometer does this by adding more or less resistance to the circuit. 2 March 87

Measuring Resistance

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Fig. 1-9 shows how the basic circuit is used for measuring resistance. First, the test probes are shorted and the zero-

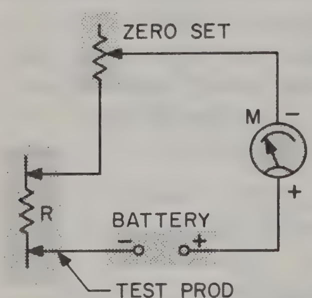

Fig. 1-9. The meter in this diagram is being used to measure resistance.

set control is adjusted so that our meter pointer is right on the last division on the far right side of the scale. Next, the test probes are placed at the opposite ends of resistor (R). Let us say that this resistor has a value of exactly 1,000 ohms. What have we done? We have inserted this new 1,000-ohm resistor in series with our circuit and doubled the total circuit resistance. If the resistance is doubled, the current is reduced to one half. Therefore the meter pointer, instead of being over at the far right, will come to rest somewhere else on the scale. We can mark this point with the number 1,000, since it is the exact value of the resistance measured. And so we can begin to set up a resistance scale of the kind exhibited in Fig. 1-5.

The VOM Battery

Whether or not we use the VOM, the battery will keep get-

ting weaker. This means, of course, that the battery will have less voltage and as a result the current flow in the meter circuit will become less. We overcome this by resetting the zero-adjust control, but when we do that the amount of resistance in the circuit is reduced. Ultimately, the time will come when the battery will be so weak that we will be unable to zero the meter. The only solution is to replace the battery in this case.

The Resistance Range

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The battery selected earlier was chosen to have a value of 1 volt for the purpose of making the example clearer. In practice, however, we would use one or more 1.5-volt batteries. If we used a single battery (actually, a single cell) we would need to have a series resistor of 1,500 ohms so that we could get 1 milliampere full-scale deflection on the same meter. We can now replace our potentiometer with a 3,000-ohm unit so that we can get a resistance of 1,500 ohms with the potentiometer control set at its center.

Now let us suppose the potentiometer gives us exactly 1,500 ohms and the battery is a fresh one supplying 1.5 volts. How can we extend the resistance range of the meter? All we need do is increase the total resistance in the VOM circuit. Let us say that we wish to have an R x 10 range, so that when the meter pointer stops at the number 150 we would be measuring not 150 but 1,500 ohms. To extend the resistance range all we need do is multiply the value of the potentiometer resistance by the range we want. If we decide on R x 10, we would multiply 1,500 by 10 and get a value of 15,000 ohms. This is the total resistance we must have in the circuit if we wish to extend the range from R x 1 to R x 10. Our potentiometer was originally set at 1,500 ohms. If we subtract this value from 15,000 we will get 13,500 ohms. Thus, to have a total of 15,000 ohms in the meter circuit we would need a series resistor of 13,500 ohms.

Fig. 1-10 shows a simple switching arrangement for the resistance measuring section. With the help of the range switch we can go from R x 1 (in which case we read the scale directly) to R x 10 (multiply every reading by 10) to R x 100 (multiply every reading by 100). While this circuit may be satisfactory for explaining how series resistance is used for increasing

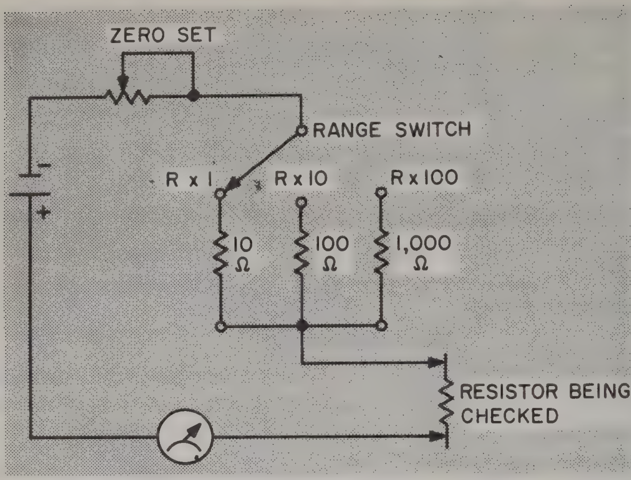

Fig. 1-10. One method for extending the resistance range of a VOM.

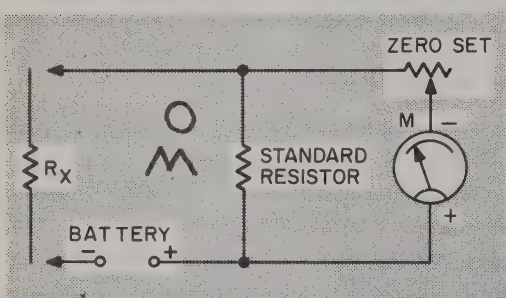

Fig. 1-11. This modified VOM circuit includes a standard resistor.

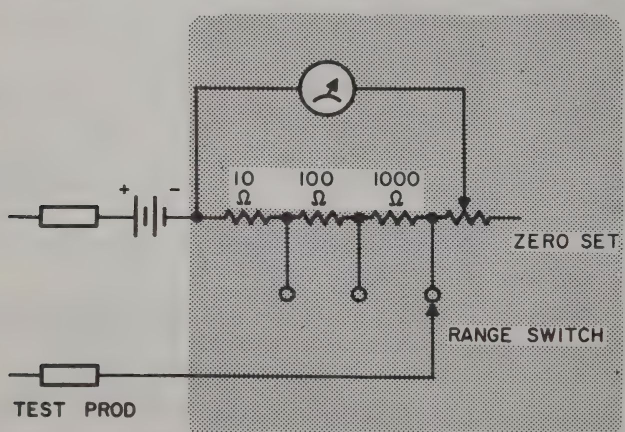

Fig. 1-12. Resistance range selector circuit for a VOM.

the range, it isn't satisfactory from a practical viewpoint. If the zero-set control is 1,500 ohms, then the value of the resistor in the R x 100 position will be close to 150,000 ohms. And with a 1.5-volt battery the maximum current will be .01 milliampere (one one-hundredth of a milliampere). This might give a reading, but the pointer would barely move a fraction of the distance along the scale. To overcome this we would need to increase our battery voltage, which means adding more batteries.

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The Standard Resistor

Fig. 1-11 shows a more practical approach to ohmmeter design. The circuit is almost the same as the one in Fig. 1-9, but a standard resistor—a precision-type with a known accurate value—is placed across the zero-set potentiometer and meter. With the test probes shorted, the battery voltage is directly across the standard resistor. The zero-set control can then be adjusted for full-scale deflection. With the test probes across resistor Rx, the additional resistance reduces voltage across the standard resistor. As a result, there is less deflection of the meter pointer. Just where the pointer will stop depends on the value of resistance being measured. The smaller the value of resistance, the more the meter needle will move toward the right.

Now suppose we wish to increase the range. Let us say that we want to have a range of R x 10 so that we must multiply every value on the resistance scale by 10. All we need do is change the standard resistance in the VOM to one that is 10 times greater. Fig. 1-12 shows one circuit arrangement that can be used. Notice that the meter, unlike the circuit of Fig. 1-10, is not in series with the range resistors, but is shunted across them. The standard resistor for the R x 1 range is 10 ohms. The standard resistor for the R x 10 range is 100 ohms, 10 times the value of the first resistor. The final resistor of 1,000 ohms, 100 times the R x 1 standard, is used for the R x 100 range.

Now let us say you are measuring the value of a resistor with a color coding of 1,000 ohms. With your VOM on the R x 1 range and your test prods across the resistor, the meter pointer should be approximately on the 1K (or 1,000) mark. But this end of the scale is so crowded it is difficult to know if the resistor is 1K, 2K, or 4K. If you now switch to the R

x 10 range, your meter pointer will move over to the right and come to rest close to the number 100. If you multiply this value by 10 (as indicated by the range switch) you will get a more accurate indication of the resistance value. The number 100, however, is still in a crowded section of the meter scale, so you might get a better reading by using another range switch setting. With the range switch on R x 100 the meter pointer will come to rest on the number 10. Here the scale is least crowded.

Why does the meter pointer move to the right as the resistance range is increased? Referring to Fig. 1-12 you can see that as the switch is moved from the lower to the higher range, the standard resistors are added to the meter shunt circuit. Thus, less current flows through the standard resistors and more current flows through the meter. Standard resistors in a VOM may have the 10 to 1 and the 100 to 1 value relationships as shown in Fig. 1-12, but the actual values will be different from those shown. The reason for this is that there are other circuit resistances to consider. The wiring, the test prods, and the battery will contribute resistance.

There is one point we have not mentioned. Whenever you switch from one resistance range to another, be sure to short your test prods and adjust the zero-set control for a zero reading on the meter. In this way you will get the most accurate reading of the resistance you are measuring.

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Meter Sensitivity

D'Arsonval meters can be obtained in a large variety of shapes, sizes, and styles. The sensitivity of a d'Arsonval meter is a measure of how much current it takes to move the meter pointer to the full-scale position. The meter used in our examples is a fairly common type known as a 1-mil movement. It takes one milliampere of direct current to make the meter pointer deflect full scale. But there are some d'Arsonval meters that require only a few microamperes to do the same thing. The smaller the amount of current required for full-scale deflection, the more sensitive the meter.

What makes one meter more sensitive than another? There are a number of factors involved. A sensitive meter would have a strong permanent magnet, a moving coil wound with many turns, an iron core having a high permeability, an extremely short distance between the moving coil and the pole

pieces of the permanent magnet, and pivots and bearings like those of a fine watch. The sensitivity of a d'Arsonval meter is specified in terms of ohms-per-volt. Thus, a meter that requires 1 milliampere for full-scale deflection, using a 1-volt battery and a series resistor of 1,000 ohms (or a 1.5-volt battery and a series resistor of 1,500 ohms), has a sensitivity of 1,000 ohms-per-volt. If the battery is a 2-volt unit (just as an example) we would need a series resistor of 2,000 ohms—or 1,000 ohms for each volt supplied by the battery—to maintain full-scale deflection (zero ohms reading).

Suppose, though, that we have a meter that requires only a half milliampere for full-scale deflection. If we were to use a 1-volt battery, the series resistor would be 2,000 ohms. This is just a simple application of Ohm's law. Such a meter, then, has a sensitivity of 2,000 ohms-per-volt—twice as sensitive as a meter requiring 1 milliampere for full-scale deflection. Thus, a meter with a full-scale deflection of 50 microamperes has a sensitivity of 20,000 ohms-per-volt. A meter that will deflect full scale with 100 microamperes has a sensitivity of 10,000 ohms-per-volt. Meters available today have sensitivities up to 100,000 ohms-per-volt.

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DC Current Measurements

Fig. 1-13 shows the basic current measuring circuit of the VOM. The meter is designed to be connected in series, so that the current to be measured flows through the meter circuit. We must observe the same precaution as we did earlier in making certain that we do not exceed the current capability of the meter movement. This means that if we are using a meter having a 1 milliampere reading, 1 milliampere is the maximum current we can allow to pass through the meter itself. But what if the total circuit current we are measuring is 10 milliamperes? Then, as shown in Fig. 1-13, we want 9 milliamperes to pass through a resistor, known as a shunt, and only 1 milliampere through the meter coil.

The current reading range of the meter can be extended through the use of a number of shunts, as shown in Fig. 1-14. The lower the value of the shunt resistor, the higher the current that can be measured. The actual shunt resistance values would depend on the internal resistance of the meter. Shunt resistors are precision units, and since the resistance of a shunt can be very low, they must be carefully wired into the

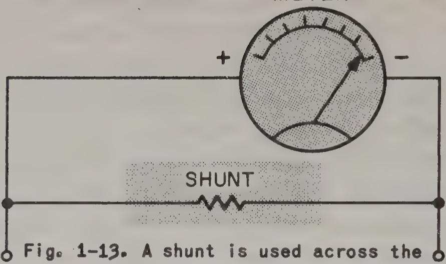


Fig. 1-13. A shunt is used across the meter in this circuit for measuring current.

meter circuit to avoid any unnecessary resistance. If a shunt has a value of only .01 ohm, you can see that it wouldn't take much in the way of a poor connection to add some resistance. Although a separate range switch is shown in Fig. 1-14, this switch would actually be part of the resistance range switch. Wafer switches are used in VOMs, so a single multi-deck wafer-type switch can be used for all the resistance, current, and voltage ranges. When making current or voltage measurements, adjustment of the zero-set control isn't re-

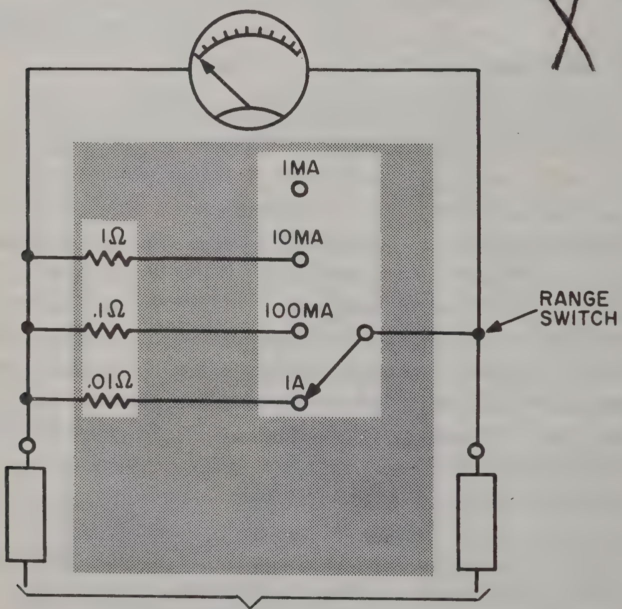


Fig. 1-14. Shunt resistors are used in parallel to extend the current reading range in this metering circuit.

quired. The zero-set is used only for making resistance checks.

DC Voltage Measurements

2 March 82

The DC voltage measuring section is much the same as the current measuring section, except that series resistors known as multipliers are used. A simple arrangement is shown in Fig. 1-15. With a 1-milliampere meter movement, 1,000 ohms of series resistance per volt is required. Thus, if we wish to measure a DC potential of 1 volt, we will need a resistor in series between the meter and the voltage. This resistor will have a value of 1,000 ohms in order to limit the meter current to 1 milliampere. But suppose we wish to measure 10 volts? Then the series resistor will have to have

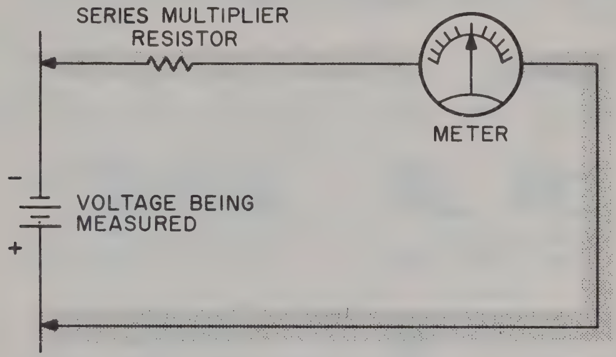
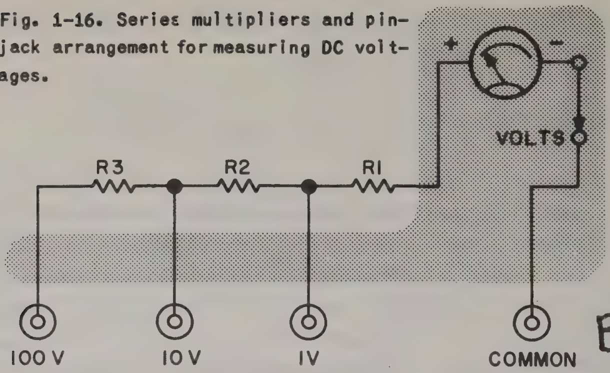


Fig. 1-15. Basic voltage measuring circuit.

10 times the value, or 10,000 ohms. This is still 1,000 ohms per volt—that is, 1,000 ohms of resistance for each volt measured. Thus, to measure 50 volts the series resistance must be 50,000 ohms (for full-scale deflection) and for 100 volts, the value must be 100,000 ohms. In each case, the resistor limits the flow of current to 1 milliampere, which produces full-scale deflection of the meter.

The switching section can be part of the wafer switch arrangement used for switching resistance and current ranges. Although the wiring to the switch becomes complicated, it has the advantage of providing a single switching control. Some VOMs use a pin-jack arrangement for connecting test leads to the instrument. Fig. 1-16 shows a typical pin jack arrangement for measuring different voltage ranges. In this case, some of the burden of having different voltage ranges is taken

Fig. 1-16. Series multipliers and pin-jack arrangement for measuring DC voltages.



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from the switching circuit. Some VOMs use combinations of pin jacks and switching to cover all their ranges. Both test leads and pin jacks are often color coded, black representing the common or "cold" lead and red the "hot" lead.

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The Meter Rectifier

The purpose of the current through the d'Arsonval meter is

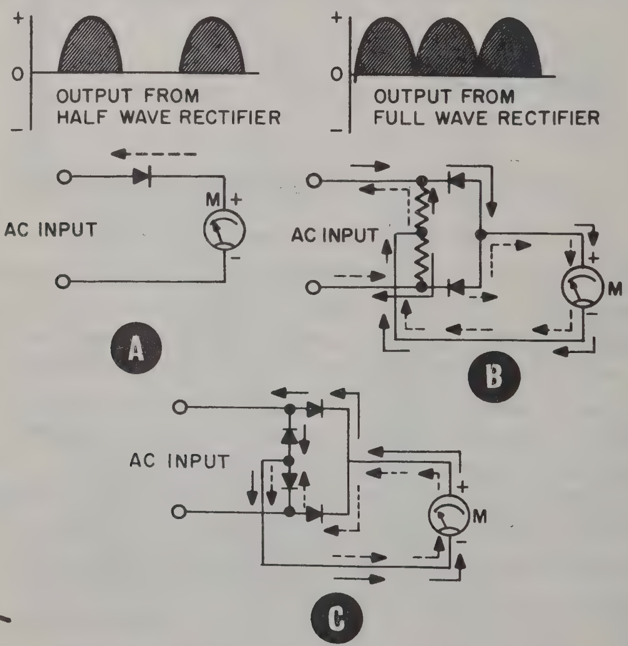


Fig. 1-17. Types of meter rectifiers. (A) Half-wave; (B) full-wave; (C) full-wave bridge. The arrows show the direction of current flow.

to make an electromagnet of the moving coil. But this moving coil electromagnet must have constant polarity, which means only direct current should flow through the moving coil. Suppose, though, that we did send an alternating current through the moving coil. What would happen? If the frequency of the alternating current was low enough, the meter needle would oscillate back and forth in step with the changing polarity of its moving coil. With a higher frequency the pointer would not move at all, but would remain quivering at the zero mark at the left side of the scale.

To use the VOM for measuring AC voltage and current, a rectifier is needed to change the alternating current to direct current. Known as a meter rectifier, the unit is quite small. The simplest type of rectifier, a half-wave semiconductor unit, is shown in Fig. 1-17A. Since this type of rectifier works on only half of the input voltage waveform, the meter receives a series of pulses.

An improved form of meter rectifier is the full-wave unit shown in Fig. 1-17B. Both halves of the input waveform are

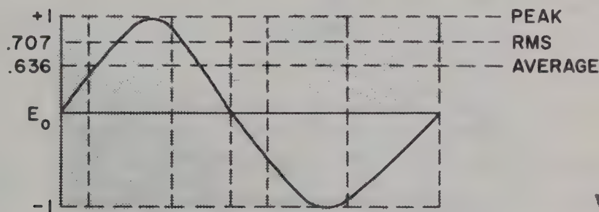


Fig. 1-18. Diagram showing relationship between peak, rms, and average values of a sine wave.

rectified so that current flows through the meter practically at all times. The full-wave rectifier uses two diodes. The arrows with the solid lines show the direction of current flow through one diode; the arrows with the dashed lines show the current through the other diode. Notice, however, that current through the meter always flows in the same direction. The full-wave rectifier is the type most often used in VOMs, but the full-wave bridge in Fig. 1-17C does provide a higher output. The only disadvantage is that it requires four diodes.

AC Input Waveform

Although the current delivered by the rectifier to the meter is an average current, the meter scales are calibrated in terms of root-mean-square (rms) values. Fig. 1-18 shows

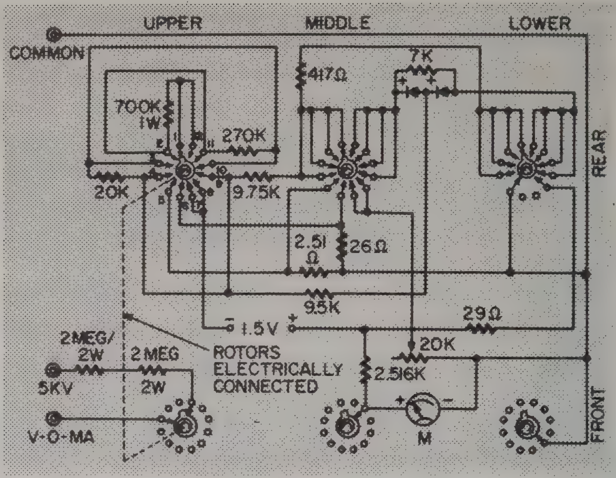


Fig. 1-19. Wiring diagram of a commercial VOM.

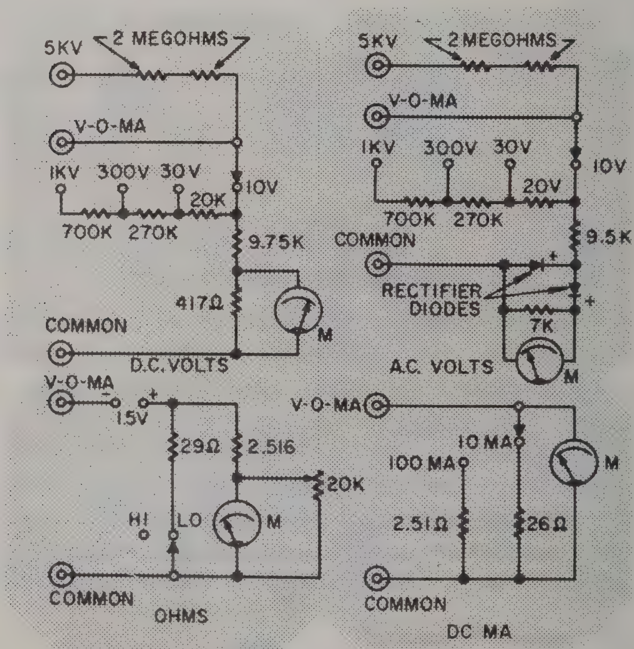


Fig. 1-20. Circuits for each of the measurement functions of the VOM in Fig. 1-19.

the relationships of average, rms, and peak currents or voltages. In this example, the waveform is a sine wave; however, many other types of waveforms are encountered in electronics. While a VOM may give you some kind of reading when measuring waveforms other than sine waves, often it will be meaningless. About all the information you can gain is that there is a voltage or current present.

AC currents and voltages are handled by the VOM in the same way as DC currents and voltages. Shunt resistors are used when measuring current, series multiplier resistors when measuring voltage. Some VOMs use the same series and shunt resistors for both AC or DC; others use separate resistors for each function. The advantage of having separate resistors for AC is that the two scales can be calibrated independently.

Commercial VOMs

The whole idea of a VOM is to have a single instrument supply as much information about resistance, voltage, and current as it is possible to get. While the individual circuits in a VOM are fairly simple, the need for using the same components for different functions makes the switching arrangements somewhat complicated. And, of course, some VOMs are far more elaborate than others.

Fig. 1-19 shows the wiring of a simple commercial VOM. There are three pin-jack connections for test leads—common; V-O-MA (volts-ohms-milliamperes), and 5KV (5,000 volts). Fig. 1-20 shows the circuit for each of the functions: DC volts; AC volts; DC current; and resistance. This instrument is designed to read 10, 30, 300, 1,000 and 5,000 volts AC or DC. In the DC current range it can measure 10 milliamperes and 100 milliamperes. It has two resistance ranges—low ohms and high ohms.

Instrument Controls

Generally, you will find three variable controls on the front panel of a VOM—zero adjust, range selector, and function selector. The function selector determines which of the circuits of the VOM (as shown in Fig. 1-20) are to be used. In a representative VOM, the function control can be set for AC volts, DC volts, DC amperes, and ohms. Both the function

Fig. 1-21. A VOM of the type widely used in servicing. (Courtesy Simpson Electric Co.)

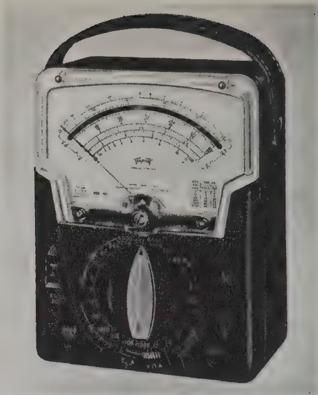


Fig. 1-22. This VOM supplies a wide choice of voltage, current and resistance measurements. (Courtesy Triplett Elect. Instr. Co.)

control and the range control must be properly set before making any measurements.

Figs. 1-21 and 1-22 show two different types of commercial VOMS. The control at the extreme left in the VOM in Fig. 1-21 is a voltage selector, either AC or DC. The center control is the range selector while the control at the right is a zero-ohms adjust. This instrument has a sensitivity of 20,000 ohms-per-volt. The VOM in Fig. 1-22 has just two controls: a zero-ohms adjust and a range selector. This instrument and the one in Fig. 1-21 are both high-quality units.

CHAPTER 2

Using the VOM

No matter what you pay for your VOM, its value can be measured only in terms of the useful indications it provides you. What you can do with a VOM—what information you can get out of it—depends entirely on your understanding of what the instrument can do and what it cannot do. It can be easily damaged through a wrong connection; its life can be shortened through improper handling.

Making Resistance Checks

The VOM meter pointer should rest normally on the final division mark on the left-hand side of the scale. It may be that it does when the instrument is horizontal, but not when it is vertical. For your particular VOM this may be normal. In any event, you should know from the instruction manual accompanying the VOM. If the meter pointer needs adjustment, locate the meter screw adjustment near the bottom of the meter face and carefully adjust until the pointer of the meter rests on the zero mark of the DC voltage scale. You should not need to turn the screw more than a fraction to correct the pointer setting. When making this adjustment, be sure to look directly at the meter—not from one side or the other. NO OBLIQUE ANGLE.

Connect your test prods to the common and resistance jacks on the front of the instrument and set the range switch on the R x 1 scale. Short the test prods. The meter pointer should come to rest near the zero mark of the ohms scale. Rotate the ohms-adjust control until the pointer is exactly on zero. Now rotate the range switch through each of its resistance ranges. You should be able to set the meter pointer on zero in each instance by using the ohms-adjust control. If you find that on one or more settings of the range switch you are unable

to reach zero with the adjustment, replace the battery. If there is more than one battery, replace them all.

To avoid unnecessary discharging of the battery, never leave your VOM with the range control set in any of the resistance positions. At regular intervals, say once every six months, open the VOM and examine the batteries to make sure they have not become corroded. If corrosion does exist, remove it and replace the batteries. The test leads should make firm contact with the pin jacks on the VOM front panel. To check, touch the prods together, with the VOM set on a resistance range. Move the leads back and forth. The pointer should remain on zero and not move. If it does, there is a poor connection and

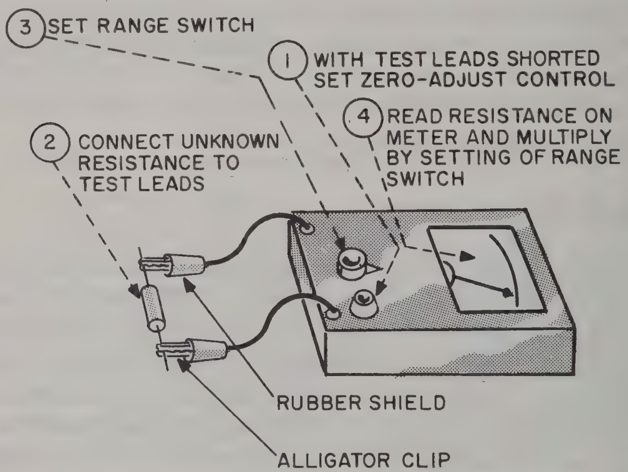


Fig. 2-1. Method for checking a fixed resistor.

it should be repaired if dependable readings are to be obtained.

Generally, when the resistance of a component in a circuit is to be checked it must be disconnected. However, if there are no components shunted across the resistor, then an in-circuit check can be made. In-circuit checks can be made only if all power to the unit is off. A resistance check with power on probably will damage the VOM. When making a resistance check, note the setting of the range control and be sure to multiply the scale reading by the value indicated on the control. Always try to choose the setting of the range control which will put the meter pointer at center scale or to the right of center scale. The resistance range of the VOM also is ideal for making continuity checks. For this you will find

it helpful to have the common lead, or both leads, equipped with alligator clips.

Fig. 2-1 shows how the resistance value of a component is checked. Here are the steps to follow:

1. With the test leads shorted, set the zero-adjust control so the meter pointer comes to rest at zero on the ohms scale.
2. Connect the test leads to the unknown resistance.
3. Set the range switch on the VOM so that the meter pointer is at center scale or to the right of center.
4. Read the amount of resistance on the resistance scale. This is generally the topmost scale on the meter and is the only scale on the meter with zero on the right-hand side. Then multiply your reading by the setting of the range switch. You may find it necessary to zero-adjust again after you have changed the position of the range switch. If, however, the meter pointer always rests on zero regardless of the range, it isn't necessary to do this. If the zero-adjust control needs constant attention—that is, if you must constantly reset it after making resistance readings—the battery most likely has become weak and should be replaced.

A resistor measured with an ohmmeter usually will measure a small amount higher or lower than the marking or color code specifies. This is because of the resistor's tolerance rating. For example, a 1 meg unit with a 20% tolerance will measure anywhere from 800,000 ohms to 1,200,000 ohms. In addition, the ohmmeter will not be 100% accurate, and its deviation from accuracy can cause a further error in measurement. A resistor having a tolerance of 5% is marked with a gold band, and one with a tolerance of 10% is marked with a silver band. Resistors of greater tolerance are not marked.

Some capacitors resemble resistors and may be color coded like them. If, in checking an unknown component, the meter pointer swings over toward zero on the resistance range, and then slowly moves back toward the left-hand side of the scale, the unit you are checking is probably a capacitor.

Checking Shunted Components

If you get no reading at all while checking a resistor, it is either open or its value is too high to give a reading. This is particularly true when measuring a resistor in the megohm

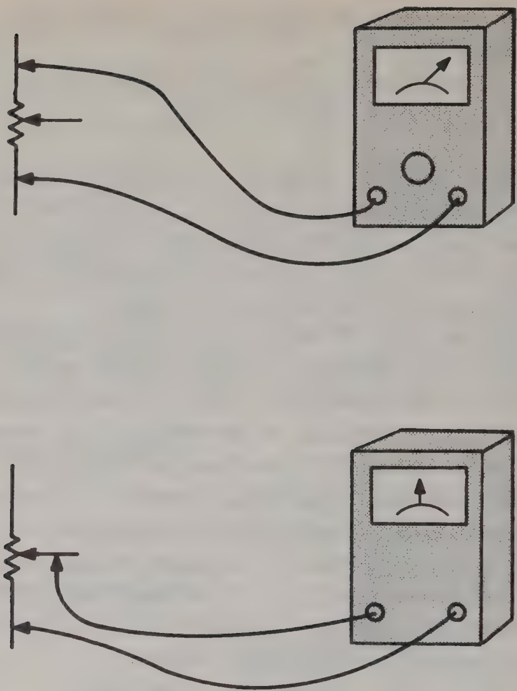


Fig. 2-2. Check a variable resistance at these points.

range with a VOM having just an R x 1 and an R x 10 range. If the resistors you are checking are wired in parallel, it will be necessary to disconnect one end of each resistor to check them separately.

Checking Power Resistors

If a power resistor has only two terminals, check it in the same way as an ordinary carbon resistor. If the unit has taps, check the resistance from one end to each tap. It is possible to get a resistance reading from the end of the resistor to the first tap and an open circuit reading from the same end of the resistor to the second tap. This indicates an open circuit between taps. If the tap is a movable one, instead of a series of fixed taps, make sure it is fastened firmly in place and making contact with the resistance element before testing. Check it in the same way as a power resistor with taps.

Some component values may vary between hot and cold conditions. The value of a resistor when hot can be startlingly

different from the resistance of the same unit when cold. To demonstrate this to yourself measure the filament resistance of a vacuum tube when hot and then again when cold.

Checking Variable Resistors

To check a variable resistor or potentiometer, follow the same steps outlined previously for checking fixed resistors. Set the range control for measuring resistance and then zero-set your VOM. If the variable resistor has three terminals, connect your VOM first to the two outer terminals as shown in Fig. 2-2. This will give you the total resistance value. Rotating the arm of the variable resistor should have no effect on the resistance at this time. Notice that some variable resistance controls are in the megohm range, so you must be sure your VOM is capable of reading such high values of resistance.

Now disconnect one test lead from either end of the variable resistor and connect it to the third terminal. Turn the control shaft slowly. The meter pointer should move smoothly from one end to the other. If the meter pointer jumps sharply at any point, the control is defective. Try various resistance ranges, though, to make sure it is the control that is defective and that the "jump" isn't due to an incorrect range setting. (NOTE: Many potentiometers, such as volume and tone controls, are nonlinear; that is, resistance at one end of the range changes more rapidly than at the other. Do not misinterpret a more rapid, but smooth, change in resistance as a "jump.")

Continuity Checking

The purpose of a continuity check, as its name implies, is to make sure that a particular conductor or a series circuit is complete. Fig. 2-3 shows the power cord connection to the receiver transformer. Such a continuity measurement provides a check of the fuse, the primary of the transformer, the line switch, and the line cord and plug. This is quite a bit of information to get from just one test. Connect the test prods to the male plug terminals and turn the on-off switch back and forth. The meter pointer should travel from the left side of the scale to some point on the scale. If the resistance scale

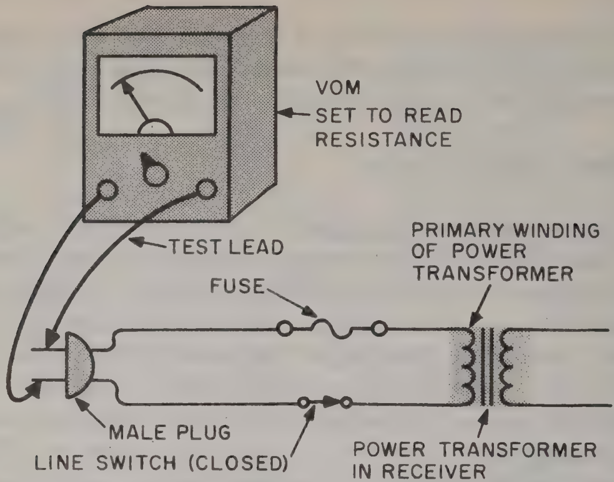


Fig. 2-3. Method for checking a power input circuit.

reads "infinite" for any setting of the on-off switch of the receiver and for any setting of the range control, the circuit is open. To determine the cause connect the test leads across the fuse and check it for continuity; then check continuity of the primary winding and each section of the line cord until you locate the open component. Obviously, the male plug must not be plugged in to the power outlet during these tests.

But what if the receiver is a transformerless type—that is, a set that doesn't use a power transformer? In sets of this type all of the tube filaments are in series, or in some TV

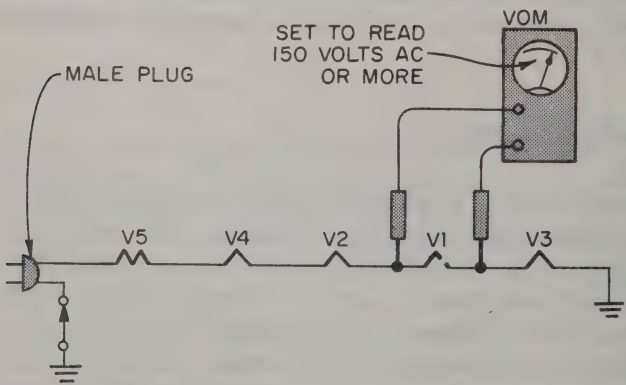


Fig. 2-4. Method for finding a tube with an open filament in a series string. The line switch must be closed and the male plug inserted in power outlet.

sets a series-parallel combination is used. If the set you are checking is a small AC-DC type, plug the receiver into the power line and turn the receiver switch to the on position. If the tubes do not light there is either an open in the line cord or one of the tube filaments is defective. If the set is a TV receiver using a series-parallel combination of tubes, about half of the tubes may be lit, with the other half inoperative.

To check the tube filaments set your VOM to read AC volts (see Fig. 2-4). The range switch should be set for a reading of 150 volts or more. Connect the transformerless receiver to the power line and turn the receiver switch to the on position. Make sure you know which are the filament pins of the tubes. Refer to the schematic diagram or use a tube manual if you have any doubt. Now, using a pair of needle-point probes, connect the VOM across the filament of each tube. If the tube is good, the VOM meter pointer will not move, or, move very little. If you get a reading that is approximately equal to the line voltage, or some high value such as 90 or 100 volts, you will have located a tube with an open filament. Equipment using series filament circuits often have shunting resistors across some filaments to maintain the correct amount of current flow in each tube. In this type circuit the voltage measured across a burned-out filament may be nearly the same as the voltage across a good tube.

Checking Long Lines

How can you check the continuity of a long two-wire line if it stretches from room to room? Or, how can you check continuity of a two-wire transmission line if one end is on the roof? You can do this, as shown in Fig. 2-5, by connecting a jumper across the conductors at one end and then making a continuity check across the other end. Set the VOM on the high resistance range and connect the alligator clips of your test leads across the open ends. Disconnect the transmission line from the receiver when making this check since the input coil will act as a short. If both conductors are intact, the meter pointer should swing over to zero, indicating continuity through the entire line.

Checking Coaxial Cables

Coaxial cable consists of a center conductor surrounded by

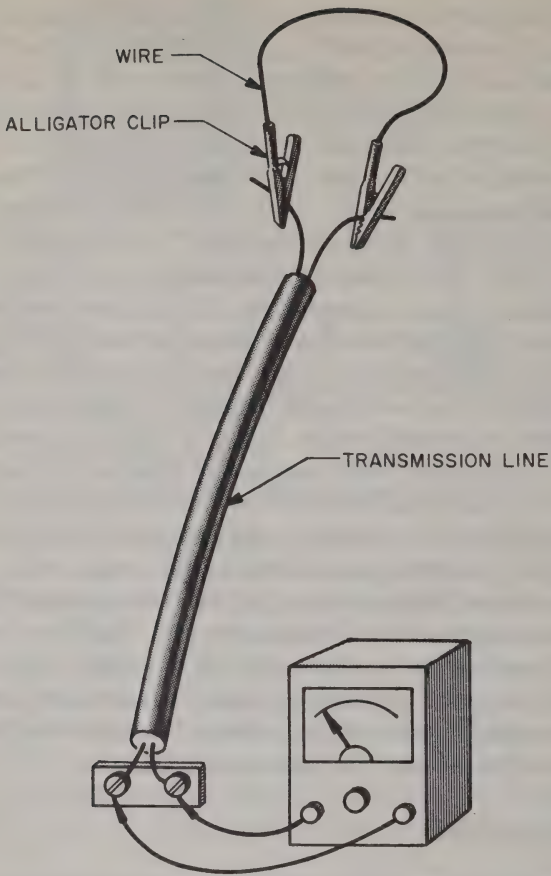


Fig. 2-5. A long line may be checked for continuity this way.

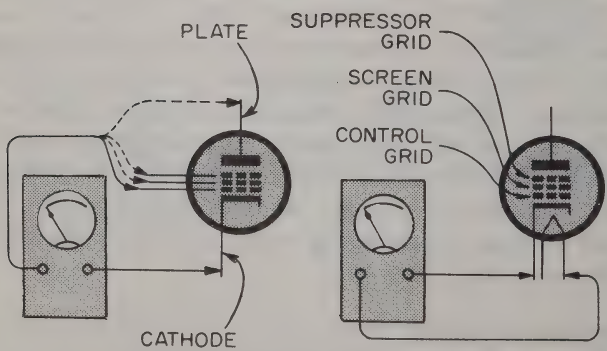


Fig. 2-6. Method of checking a tube for shorts.

insulation and an outer shield of braided metal. The center wire and the shield act as a pair of conductors but it is always possible for a metal "hair" of the shield braid to touch the center conductor and cause a short. To check, set the VOM on a high resistance range. Connect one lead to the center conductor of the cable. Touch the shield braid with the other test lead. The meter pointer should not move. Wiggle the cable during this test to see if you get a short with the cable in some other position.

Checking Wafer Switches

Rotary wafer switches can be easily checked with a VOM. Set the VOM to read resistance and connect one test lead to the rotor of the switch. Connect the other lead to each switch connection in turn. Rotate the switch; as it makes contact with the particular connection being tested, the meter pointer should swing over to zero.

Checking Variable Capacitors

Set the VOM on the resistance range and connect one test lead to the rotor of the variable capacitor and the other test lead to the stator connection. Turn the capacitor shaft slowly. The meter pointer should not move from the left side of the scale. Any flicker of the meter pointer or any movement of the pointer to the right on the scale indicates a short in the capacitor.

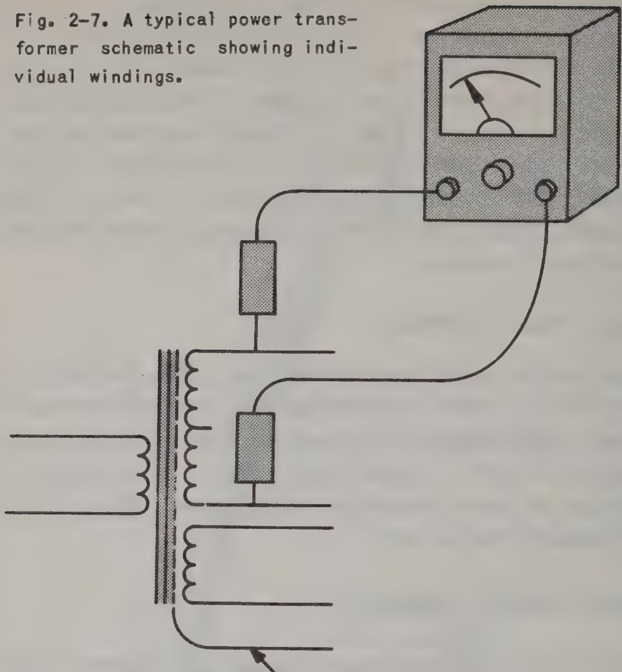
Checking Relays

A relay is simply an electromagnetically-operated switch. To check a relay, connect the coil to its voltage source so it will receive current. Set the VOM on a high resistance range and touch the test prods to the relay contacts (<u>not</u> to the coil connections). Do not use alligator clips as the moving elements of the relay may not be able to carry the weight. Check the relay contacts for closed and open circuit conditions just as you would a switch.

Checking Tubes

You can use your VOM to test tubes for filament continuity and shorts between elements, as shown in Fig. 2-6. To check

Fig. 2-7. A typical power transformer schematic showing individual windings.



filament continuity, connect the VOM across the filament pins with the VOM set to read resistance on the R x 1 scale. To check for shorts between elements set your VOM on a high resistance range. Put the tube in a receiver and let it operate long enough to get hot. Remove the tube from the receiver and connect one lead of the VOM to the cathode pin and the other to the filament. There should be no movement of the meter pointer. Tap the tube while making this test. Any movement of the meter pointer means you have an intermittent short. Repeat the test by moving the test lead from the filament to the control grid, then to the screen grid, and then to the suppressor grid. If the suppressor grid is internally connected to the cathode, as it is in some tubes, you will get an indication of a short, of course. In this case, refer to a tube manual.

Since shorts are most likely to occur between adjacent elements, a thorough check should include additional high-resistance measurements between control and screen grids, screen and suppressor grids, and suppressor grid and plate. You can perform these tests with the tube in its socket, but

after you have heated the tube, make sure you pull the line plug out of the power outlet.

Checking Transformers

If you have an unmarked transformer or one without color-coded leads, you can find the start, finish, and center tap (if any) of the windings with an ohmmeter. You may, from the resistance readings, possibly determine the leads for primary winding, the plate winding, and the filament windings of a power transformer. If the transformer is an audio output type, you will at least be able to learn which are the primary and which are the secondary leads.

Fig. 2-7 shows how to make transformer continuity checks. If the transformer is completely unmarked, select any lead at random. Connect one test lead to it with an alligator clip. Set your VOM on a high resistance range and touch each of the other leads, in turn, until you get a reading. When you get a pair of leads that show continuity, put a tag on them and make a note of the resistance reading. To do this you may need to switch to a lower resistance range on the VOM. Use the same process to check all other leads until you have matched all the pairs.

You may find three leads which show continuity. This would then be a winding with a center tap. The resistance of one lead to the center tap is most likely the same as the resistance from the center tap to the other lead. If there is a difference in resistance, the winding tap may not be at the electrical center because of the required design. To determine whether or not this is the case, check the schematic diagram or the parts list of the receiver in question. You may end up with a single lead that does not show continuity to any of the other leads. If this lead is completely uninsulated, it may be connected to a shield, known as a Faraday screen, between the primary and secondary windings of the transformer. Again, the schematic diagram may indicate whether or not this is true.

If the unit you have been checking is a power transformer, the primary leads will be those having about 2 to 8 ohms resistance; the secondary leads will be 30 ohms or more, perhaps even several hundred ohms. The filament leads will be less than 1 ohm.

You can check audio output transformers in the same way.

The two leads having a very low resistance, usually less than 5 ohms, will be the leads that connect to the voice coil in the speaker. The two leads showing a much higher resistance will be the primary leads. If the primary has three leads, one of them is a center tap. You can determine which lead is

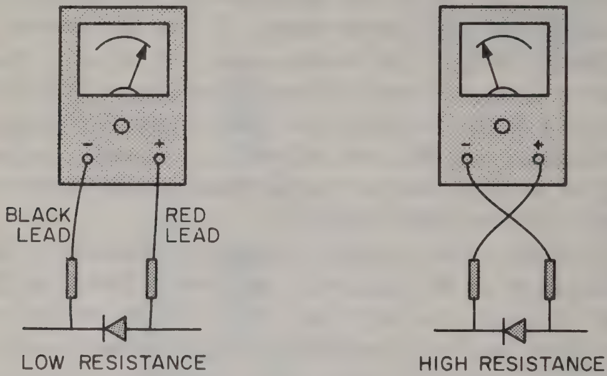


Fig. 2-8. Method for checking rectifier and demodulator diodes.

the tap by resistance checking. This applies to output transformers used with tubes and also those used with transistors.

Checking Capacitors

Set the VOM on a high resistance range and connect one lead to a terminal of the capacitor. The capacitor should not be connected to other components or should be disconnected from its circuit at one end. Touch the other capacitor terminal with the other VOM test lead. The meter pointer should swing over and then return gradually to the left side of the meter. The larger the capacitance, the longer it will take for the capacitor to charge and for the resistance reading to approach infinity. If the meter pointer does not show this charging effect, the capacitor may be defective. It should be noted that large electrolytic capacitors normally will not charge beyond a reading of 25 to 50K ohms. This is because the low battery voltage of the VOM is insufficient to overcome the inherent resistance of such units and fully charge the capacitor.

While this method of checking capacitors is crude, it will reveal shorted capacitors and capacitors which are intermittent or leaky. The difficulty with this particular test is that some capacitors are self-healing, particularly electrolytic

types, and may seem satisfactory when subjected to the low voltage of the VOM battery. However, breakdown often occurs under the much higher voltages encountered in normal operation.

Checking Semiconductor Half-Wave Rectifiers

With the rectifier disconnected from its circuit, set your VOM on its high resistance range. Put the test prods across the rectifier terminals and note the resistance reading. Transpose the test leads and note the resistance once again. (See Fig. 2-8.) The ratio of the two resistances should be at least 20 to 1. One of your readings should be much greater than the other. If the low resistance reading is 25,000 ohms, the high resistance reading should be at least 500,000 ohms. If the resistance readings are the same, or if the ratio is less than 20 to 1, the rectifier should be replaced. If the resistance readings are both high, the rectifier unit is open; if the resistance readings are both low, the unit is shorted.

If the rectifier you are checking is a full-wave stack, it will consist of two diodes. If it is a full-wave bridge, it will have four diode sections. Check each diode, in turn, separately. If any one of the diodes does not have at least a 20 to 1 resistance ratio, replace the entire unit.

Checking Semiconductor Demodulator Diodes

Diodes used as detectors or demodulators can be checked in the same way as rectifiers (Fig. 2-8). The resistances of diodes may vary considerably, but the diode should have a low resistance with the VOM test leads connected one way, and a high resistance with the leads transposed. A resistance ratio of a least 20 to 1 indicates that the diode is neither open nor shorted.

КАКОЈЕОБИЧНО

Checking Loudspeakers

To check a speaker, set your VOM on its low or medium resistance range and connect one test lead to the voice coil of your speaker as shown in Fig. 2-9. Now rub the other test prod needle point against the other voice coil terminal. As you do you should hear a slight crackling noise and, at the same time, you should get a deflection on the meter scale.

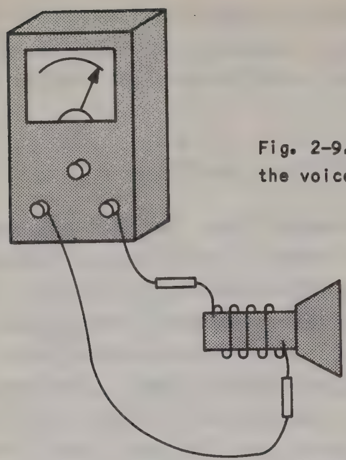
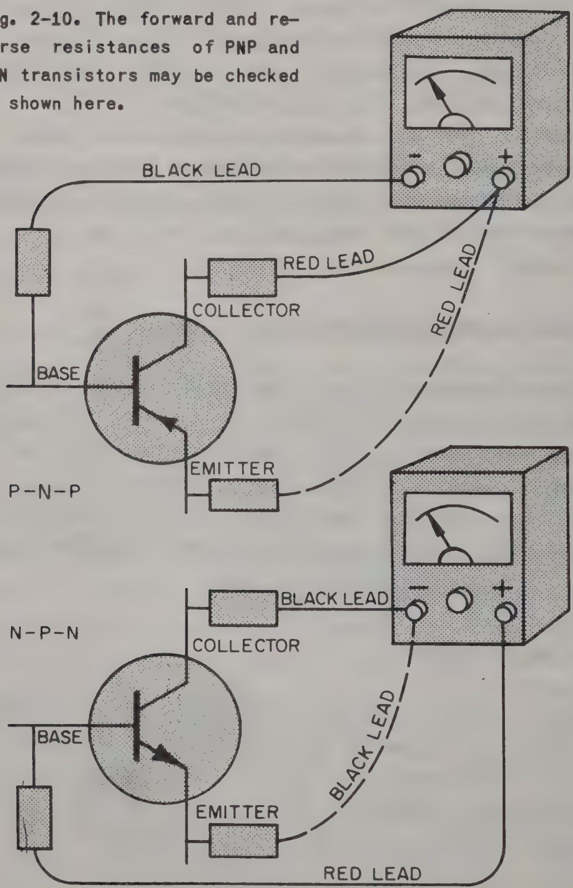


Fig. 2-9. Method for checking the voice coil of a speaker.

Fig. 2-10. The forward and reverse resistances of PNP and NPN transistors may be checked as shown here.



If you hear no sound and you get no meter readings you have an indication of an open voice coil.

Checking Transistors

You can check transistors with your VOM in the same way as for diodes. This is easy to do if you regard the transistor as a pair of diodes connected back to back. Transistors are available as NPN or PNP units. Fig. 2-10 shows how to check both types. Set the VOM to measure resistance. For a PNP unit, connect the black or common lead to the base of the transistor. In turn, touch the red lead to the collector and emitter. In both instances you should get a low resistance reading. Make a note of the readings. Transpose the leads by putting the red test lead on the base and the black test lead on the collector and then on the emitter. You should get a much higher resistance reading this time. The ratio of the resistance readings, as in the case of diodes, should be at least 20 to 1, preferably more.

When testing an NPN transistor you can follow the same procedure. As shown in the drawing, for the low or forward resistance connect the red test lead to the base and the black lead to the collector and then to the emitter. Note the resistances and then transpose the test leads, just as you did when checking the PNP transistor. This time you should get a high or reverse resistance. The ratio of the reverse to the forward resistance should be at least 20 to 1.

AC Voltage Measurements

The AC scales on your VOM may be shown in red. If you will look at the extreme left-hand end of your AC scale you will see it is nonlinear, although the remainder of the scale is linear. Try to use a scale which will permit readings to be made on the right side of the scale. The reason for the crowding of the left side of the AC scale is due to the nonlinear characteristics of the meter rectifiers at low AC voltages.

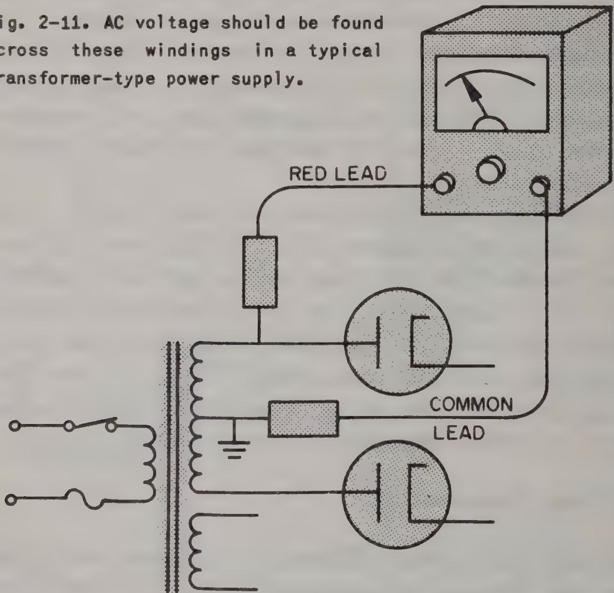
Unlike resistance measurements, which use internal battery power of the VOM, voltage measurements require that the unit being tested supply the power. You should do two things whenever you make any voltage test: (1) Make sure that your range control, which also works as a function selector, is set to read <u>volts</u>; (2) Also make sure it is on its

highest range. If you forget and keep the range switch set to read resistance or low voltage, you may ruin the meter.

Checking Line Voltages

With the VOM properly set to read high AC volts, insert the needle-point test prods into a convenient AC outlet. Handle the test prods only by the insulated portion. Keep your fingers off the metal ends of the prods or you will be inviting a shock. If the range you have selected is too high—such as 1,000 volts, for example—switch to the next lower range. If this range is 250 volts, you will be reading about center scale. Do not switch to a lower range. When making voltage tests,

Fig. 2-11. AC voltage should be found across these windings in a typical transformer-type power supply.



it is always best if you have some idea of the strength of the voltage to be measured. If you do not, try to get a reading while at the highest voltage range. Never set the range control below the voltage you intend to measure.

Fig. 2-11 shows the measurement points for the AC voltages you can measure across a power transformer. In a typical power supply the voltage across the transformer primary will be 117 volts; voltage across the full secondary will be about 600 volts, and from 2 to 12 volts across each filament winding. You should get an equal amount of voltage when checking from the center tap to either rectifier plate. Naturally, the volt-

ages we have mentioned here will vary, depending on the transformer used and its application. Also, some areas have higher or lower line voltages than is standard.

When checking the transformer, put your test leads across the primary. You should measure full line voltage here. If you do not measure any voltage, you may have an open fuse, defective line cord, or a defective plug or outlet. Check across the line cord at some point before the fuse. If you get an indication of line voltage, the fuse is open. Check before and after the line switch to see if the switch is defective. Check the outlet to make sure it is delivering voltage.

If all primary voltages are OK, move over to the secondary and make voltage checks. Connect the common or black test lead to the chassis or B minus (as shown by the ground symbol) and touch the red test lead to the input of the rectifier, as shown. The voltage should be high AC, ranging from 125 to 150 volts in a radio receiver to 250 to 350 volts in a typical TV set. If the tubes in the receiver do not light, check the filament winding for voltage.

Checking Switches

You can check switches quite easily using the AC section of your VOM. This test is not only helpful for radio and TV receivers, but for any electrical appliance that requires a switch. Since a switch is a mechanical device that gets fairly constant use, it is a component to be regarded with suspicion when electrical equipment stops working.

To check the switch, follow the procedure shown in Fig. 2-12. Since you will be checking at line-voltage level, set your VOM to read AC volts, preferably using a 250-volt scale if your VOM has one. First, check for AC voltage across the two leads going into the electrical equipment. When doing this the switch must be in its closed position and the line cord must be plugged into the power line. If you get no voltage, move one lead to the other side of the switch. If you get a reading then, you know the switch is defective. But if you still get no line voltage move the other test lead to the other side of the fuse. If you measure line voltage, the fuse is open.

There are a few things you should remember about measuring AC voltages with your VOM. As stated earlier, your VOM may be designed to measure sine-wave voltages only.

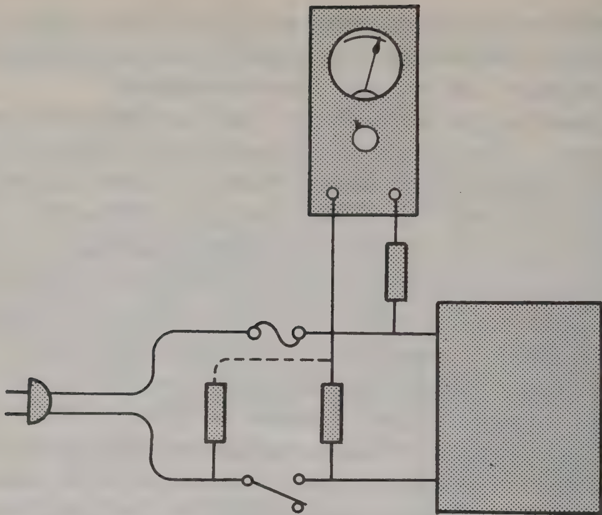


Fig. 2-12. Method for checking the AC voltage input to any electrical apparatus.

There are many other waveshapes, especially in television sets. A few VOMs are designed to measure peak-to-peak values of voltages other than sine waves; however, since such units depend on demodulation circuits to detect voltage levels, obviously the value indicated will vary with the complexity of the waveshape. And the fact that a voltage is a varying one does not make it AC. The voltage may be a DC pulse.

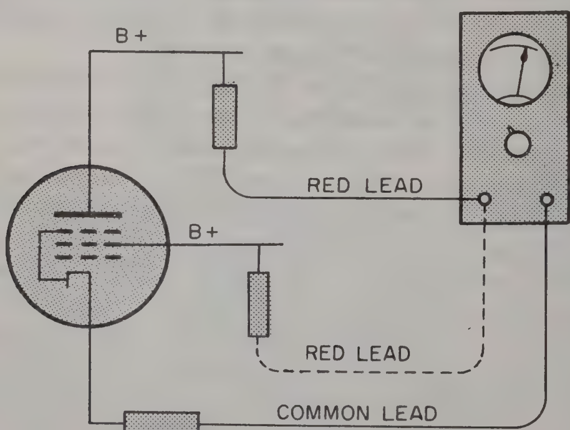


Fig. 2-13. Sketch showing the plate and screen voltage relationships to a tube cathode.

Checking DC Voltages

Your VOM probably has three voltage scales, shown in black, for DC voltage measurements. Thus, a typical VOM might have scales of 10, 50, and 250 volts maximum, plus a range multiplier that goes to 1,000 volts. It may also have a special pin-jack connection for 5,000 volts. Many VOMs have scales calibrated in multiples of 3—such as 6, 60, and 300 volts.

When measuring voltage, remember that your meter movement is drawing current for its operation from the circuit you are checking. For example, if you are checking the plate voltage of a tube whose plate current is only a few milliamperes, and if your VOM meter requires a milliampere of current for full-scale deflection, the voltage at the plate of the tube may appear to be lower than it really is. A VOM that requires only 50 microamperes for full-scale deflection will have much less effect on the voltage of the circuit it is measuring.

Measuring Tube Voltages

The operating or effective voltage on the plate or screen grid of a tube is the voltage appearing between these elements and the cathode. Fig. 2-13 shows how to measure these voltages. Set the VOM to read high DC volts and connect the black or common test lead to the cathode. In turn, connect the red or "hot" test lead to the plate and then to the screen grid. When the cathode is connected directly to ground, or through a low value resistor (100 ohms or less), it may be more convenient to connect the black or common lead to the metal chassis or B minus bus of the receiver you are checking. This also can be done when checking tube circuits in which the cathode and grid are operated above ground by subtracting the cathode voltage-to-ground measurement from the plate and screen measurement. However, this method is not quite as accurate as the direct plate-to-cathode measurement.

The bias voltage of a tube is the DC voltage between control grid and cathode. To measure this voltage, use the test setup shown in Fig. 2-14 The bias is usually just a few volts for common amplifiers.

Troubleshooting A Tube Circuit

In Fig. 2-15A we have a tube circuit connected to a power

BLACK/COMMON LEAD/B—

NCTO

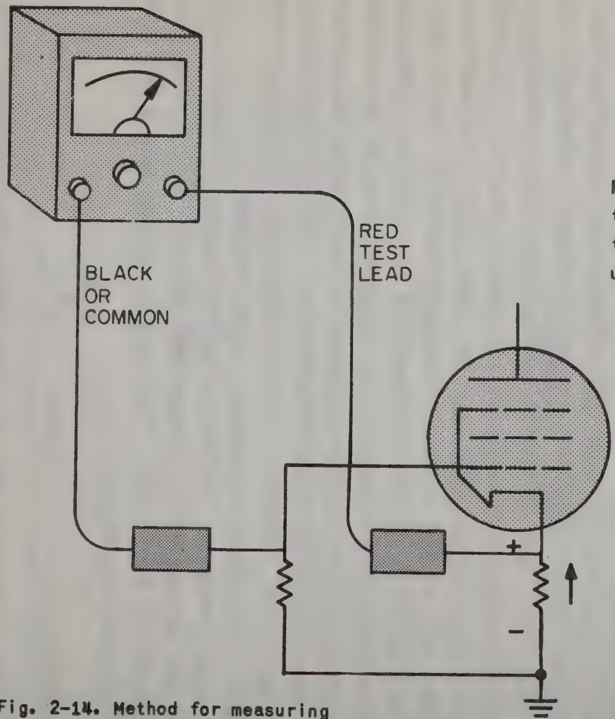


Fig. 2-14. Method for measuring tube bias.

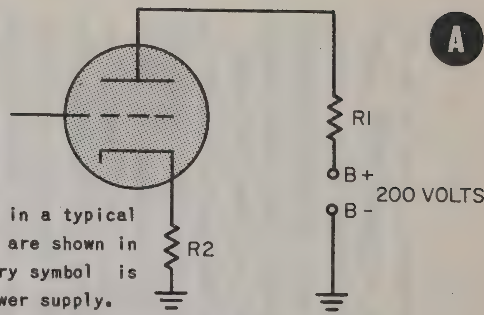
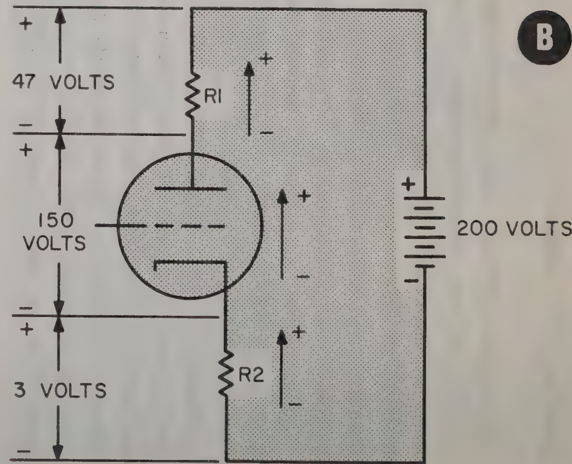


Fig. 2-15. Voltage drops in a typical triode amplifier circuit are shown in this drawing. A battery symbol is used to represent the power supply.



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supply that delivers 200 volts DC. The plate voltage is supposed to be 150 volts when the tube is not receiving a signal and the bias is 3 volts. The bias is supplied by the resistor in the cathode circuit.

Fig. 2-15B shows that this circuit is really just a voltage divider with 47 volts DC across load resistor R1, 150 volts across the tube (that is, between plate and cathode), and 3 volts across cathode resistor R2. Notice the polarity of the DC voltage across each component. It is important to know this, since it tells us how to connect the red (hot) and black (common) leads of the VOM. To check the circuit, set the VOM on a high DC voltage range and measure the voltage between cathode and plate of the tube, with the black lead on the cathode and the red lead on the plate. If the range you have selected is too high, turn it to a lower one.

Suppose you measure 200 volts on the plate of the tube instead of 150. This probably means that no current is flowing through the tube and that you are not getting voltage drops across R1 and R2. A possibility may be that the tube is defective, or for some reason there is no current from cathode to plate. If, on the other hand, the voltage on the plate of the tube is much less than 150 volts, too much current is passing through the tube. This could happen if the cathode resistor decreased in value or if positive voltage is being applied to the grid.

You can measure the bias voltage by connecting the black or common lead to the chassis or at the bottom of R2 and the red lead on the cathode pin. You will need to reduce the voltage range so that you can read the low voltage. In the same way, measure the voltage across load resistor R1. Be careful—the negative or black (common) lead of the VOM must connect to the plate of the tube and the red lead to the other end of R1. In making this measurement if you get some reading approaching 200 volts, instead of a normal value, the resistor may be open. You can check the voltage source by setting the VOM on a high DC voltage range. Connect the common lead to the chassis and the other lead to the B-plus line. One end of R1 is a convenient checking point.

The tube shown in Fig. 2-15 is a triode. If you have a pentode tube, as shown in Fig. 2-16, you can check the voltage at the screen grid pin and the voltage across the screen grid resistor in the same manner described for plate circuit tests.

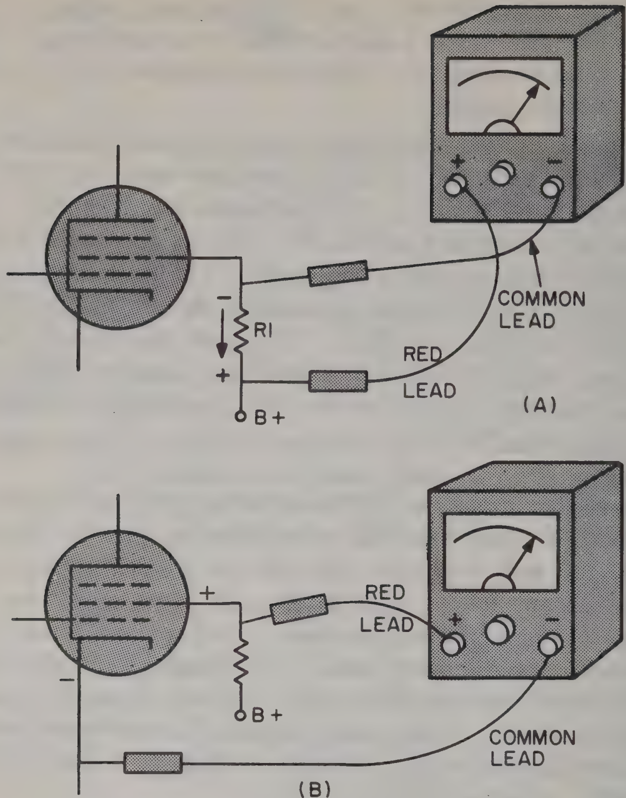
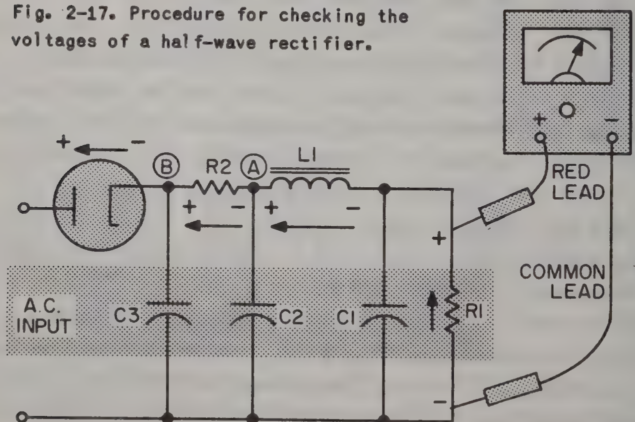


Fig. 2-16. (A) Method for checking the voltage across screen dropping resistor. (B) Checking the voltage at the screen grid.

Fig. 2-17. Procedure for checking the voltages of a half-wave rectifier.



Set your VOM to read high DC volts and connect the red test lead to the screen grid. Connect the black (common) test lead to the chassis or cathode of the tube. If there is no voltage reading, resistor R1 is open. You can measure the voltage across R1 in this diagram in exactly the same way you measured the voltage across R1 in Fig. 2-15.

More Checks on the Power Supply

Fig. 2-17 shows a half-wave rectifier type of power supply using resistor R2 and choke coil L1 as filter units. As a start, set your VOM to read high DC volts and connect the common test lead to the chassis or B-minus, as the case may be. Touch the red lead to the output side of the filter choke (L1 in the drawing). If you get no voltage reading, move the red test lead to point A. You will actually be measuring the voltage across filter capacitor C2. If you get a voltage reading here, but did not get one when checking across R1, then choke coil L1 is open. Now move the red test lead to point B. Here you will be measuring the voltage at the output of the power rectifier. If you get a voltage reading here, but did not get one at point A, filter resistor R2 is open.

In making these tests you can see that we did not move the common test lead. It remained where it was and the red test lead was used to probe successive points in the power supply. In this way you can easily find just where the voltage stops and pinpoint the component that is causing the trouble. Although the circuit shown in Fig. 2-17 uses a tube as a rectifier, you can check a power supply using a semiconductor rectifier in the same way. Some power supplies use a single resistor as a filter; others, as the one shown in Fig. 2-17, are more elaborate. The test procedure is the same, though.

Voltages are not always measured with respect to chassis. For example, with some equipment the AC power input is isolated from the chassis to reduce the danger of shock resulting from grounding of the power line when the line plugs happen to be reversed. To measure voltages accurately on such chassis, the test leads must be connected across the points where the voltage is present. Also on such chassis the rectifier filament may be at a high DC voltage with respect to the chassis. When you want to check the filament voltage in this case, the test prods must be connected to the filament

terminals without touching the chassis. Usually, if the measured voltage is high or low by 20% it is possible that the voltage source is the cause of trouble, especially if the equipment is operated from batteries. Of course, a voltmeter can be inaccurate also, and this fact should be taken into consideration when making measurements.

20% or less is bad

Checking Batteries

Ø Battery Common is Minus

You can use your VOM to check batteries, but only while they are being used in normal operation (in its equipment and the equipment operating). Even a battery that is almost dead may indicate full voltage or close to full voltage if it is checked out of circuit. To check a battery, connect the red test lead to the plus terminal of the battery and the common test lead to the negative terminal. With the receiver or other equipment turned on, make a note of the battery voltage. If it is 20% or more below normal replace the battery. If it is a rechargeable type, of course, the remedy is to recharge it.

Taking Care of Your VOM

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There are a few simple do's and don'ts you should follow so you get the most out of your investment in a VOM.

- When not using the instrument, turn the function switch off, or to DC volts.
- Always start with the highest scale.
- Zero-set the VOM before making resistance checks.
- Check the condition of the battery (or batteries) at least once every three months. Replace all batteries if you cannot zero set the meter.
- Know the polarity of the voltage you are checking.
- Never measure resistance with current flowing in the circuit.
- Keep your meter away from any component that has a strong magnetic field.
- Do not adjust the meter pointer with the set screw on the meter face unless it is absolutely necessary.
- Clean your meter with a slightly damp cloth once in a while.
- Do not use any abrasives, soaps, detergents, or oils.

CHAPTER 3

Servicing With the VOM

If you ever want to start a lively discussion among service technicians, just ask them to name their favorite test instrument. Generally, the debate will narrow itself down to three —the VOM, the VTVM, and the scope. Some technicians like the portability of the VOM. Others are VTVM-happy. Then there is a group that makes the scope the central instrument on the test bench.

Who is right? They all are!

One of the reasons for the argument is that there is a certain amount of duplication among these instruments. You can use a VOM, a VTVM, or a scope to measure voltage. You can use either a VOM or VTVM to measure resistance. But that's really not the point. The important factors are: How conveniently can you make the measurement? How accurate must the measurement be? Obviously, it's silly to make a current measurement when a voltage measurement will do. A current measurement requires opening a circuit; a voltage measurement does not. But is it wise to make a voltage measurement when a resistance measurement will do? A voltage measurement means that the receiver or circuit being checked must be "on"—it must be getting power. A resistance measurement has no such requirement.

Most service technicians have all three of these three basic instruments, because they know from experience that each instrument can make its own contribution to better and faster servicing. As a general rule, the VOM is liked because of its portability. The VTVM is needed since its high input impedance is a must under certain circuit testing conditions. And only the scope can show you what waveforms look like. This Chapter concentrates on servicing techniques and typical troubles you can diagnose with a VOM. Obviously, for almost all of the common tests and measurements described, you

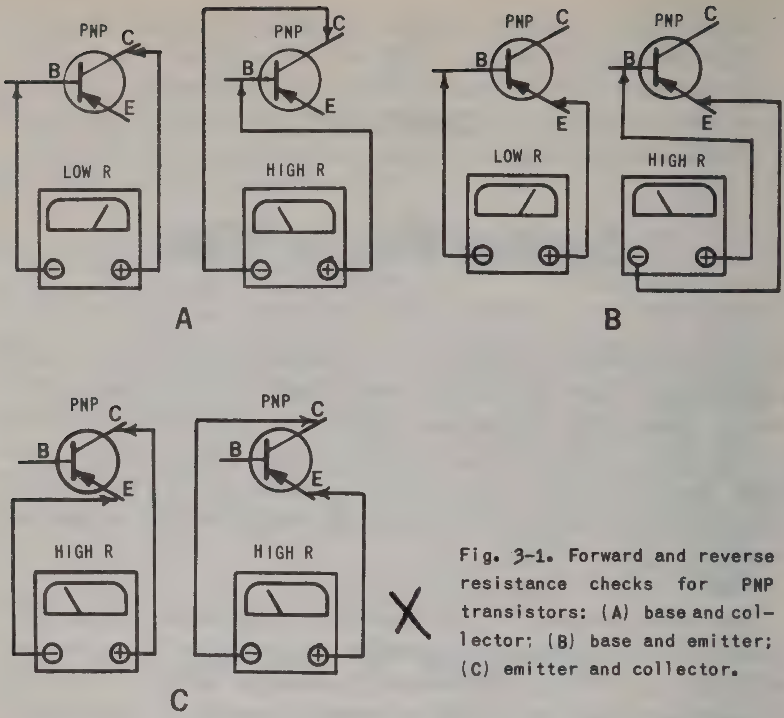


Fig. 3-1. Forward and reverse resistance checks for PNP transistors: (A) base and collector; (B) base and emitter; (C) emitter and collector.

can perform them as well with a VTVM, or in some cases even a scope. You can, for example, check an oscillator with a VOM, a VTVM, or a scope. With time and experience you develop your own instrument preference.

Testing Transistors and Diodes

Diodes and transistors are usually wired (soldered) into a circuit and therefore are not conveniently removed for testing like tubes. Unsoldering transistors and diodes can be a replacement nuisance, especially in the very close quarters of

Table 3-1. Transistor Resistance Ratio (See Fig. 3-1).

PNP	NPN	BASE	EMITTER	COLLECTOR
low	high	–	+	open
high	low	+	–	open
low	high	–	open	+
high	low	+	open	–
high	high	open	–	+
high	high	open	+	–

a PC board. Nothing can be more aggravating or time-consuming than to replace a component you thought was good. However, it's easy to check diodes and transistors with a VOM before making a replacement. All you have to do is check forward and reverse resistance and set it up as a ratio. The previous Chapter discussed how to make forward and reverse resistance checks between the elements of a transistor. The important thing is to note the polarity of the VOM leads. You must know the minus and plus terminals. For a PNP transistor you should get a low resistance reading between base and collector with the minus lead of the VOM on the base and the plus lead on the collector (see Fig. 3-1). With the test leads reversed, the resistance reading should be much higher. By dividing the high resistance reading by the low resistance reading you will have a ratio that will give you an indication as to the workability of the transistor. Any ratio higher than 100 normally can be considered good, although some transistors will have a lower forward-to-reverse ratio.

If you don't have a transistor tester, you'll find this quick check of transistors helpful. As an aid you can use Table 3-I to help you check both NPN and PNP types. These tests must be made with the transistor out of the receiver, or else in the receiver with other components disconnected. The power switch should be off or the power source otherwise disconnected.

No Sound: Single-Ended Audio Amplifier Stage

You've checked out every stage in a transistor receiver and they all work, except the output stage. Table 3-II shows some possible troubles and how you can use your VOM to find them (see Fig. 3-2). The tests indicated are for a transistor audio amplifier, but the same tests can be used for a tube-type amplifier. Absence of sound means that some component is open or is shorted. Generally, a changed-value component will not produce a trouble of this kind. The usual trouble in a dead transistor radio, though, is a dead battery. Having a receiver with no output is really a stroke of luck since the trouble is stable and ordinarily easy to find. Other difficulties, such as low volume, distortion, or intermittent sound may take a little longer to trace. Table 3-III shows some typical output stage difficulties (see Fig. 3-3).

If you are confronted with a push-pull audio stage (Fig. 3-4),

Table 3-II. Causes For Inoperative Audio Amplifier (See Fig. 3-2).

TROUBLE	VOM CHECK
Open voice coil.	This doesn't happen often, but the voice coil leads can corrode at their connecting points. Resistance check the voice coil with VOM function selector on OHMS and range switch in low position. Resistance reading should be close to zero. Disconnect one lead of voice coil when making this test.
Open output transformer.	Resistance check primary and secondary windings. Primary resistance should be higher than secondary. Primary winding is sometimes shunted by a capacitor. Resistance check both transformer and capacitor with leads disconnected.
Open emitter resistor	Turn receiver on and advance volume control to maximum. Measure voltage drop across emitter resistor. If no drop appears, no current is flowing through transistor. Voltage drop across emitter resistor will be small. Set VOM on low voltage range. Trouble could be due to open emitter resistor or shorted emitter resistor bypass capacitor.
No forward bias.	Measure voltage drops across forward bias resistors R1 and R2. No voltage across these resistors indicates open R1 or R2, defective connection to battery, or completely run-down battery.
Open coupling capacitor.	Coupling capacitor C1 may be open. Shunt with an equivalent capacitor. If capacitor is polarized, make sure to connect capacitor correctly.

Table 3-III. Causes For Typical Audio Amplifier Troubles (See Fig. 3-3).

TROUBLE	VOM CHECK
No output signal.	If you have the manufacturer's circuit diagram, set your VOM to the 10-volt scale and see how close your measurements compare with those given. A missing voltage means an open component. If the voltages at the transistor elements are higher than normal, the transistor is not conducting.
No output signal or intermittent signal.	A component shown in Fig. 3-3 not illustrated in Fig. 3-2 is a headphone jack. Jacks for transistor receivers are tiny components which sometimes short. A short will kill the sound for both phones and speaker. Sometimes the short barely makes contact, resulting in a receiver that plays intermittently.
Low volume.	Low volume, with distortion, usually means that the batteries are crying for replacement. Take a look at the emitter bypass capacitor, a high capacitance electrolytic. If volume is low, a replacement capacitor may be called for. Sometimes low volume is due to a combination of troubles. A weak battery and an emitter bypass that has opened or lost capacitance can collectively contribute lower volume. When replacing batteries, volume control should be in low position when set is tuned to strong stations. If volume control must always be fairly well advanced, look for other troubles.
Distortion.	A weak battery usually produces distortion. Check emitter resistor and the resistors supplying forward bias (R1 and R2 in Fig. 3-3).
Oscillation.	Capacitor C2 from collector to base is a neutralization capacitor. If open, stage can oscillate.

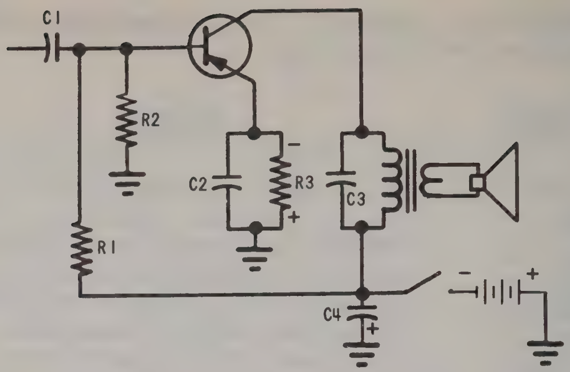


Fig. 3-2. Single-ended transistor audio output stage. Once signal tracing has earmarked this stage as the troublemaker, a VOM can be used to localize the defective component.

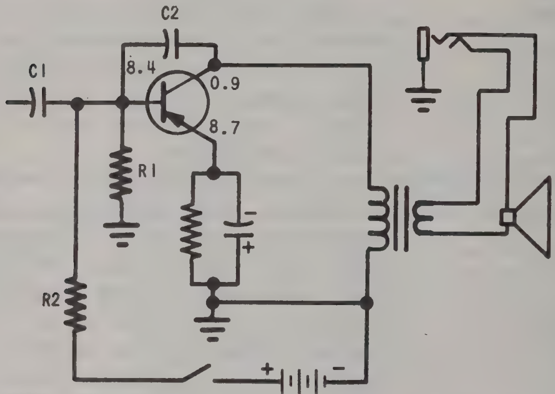


Fig. 3-3. Another version of the single-ended transistor audio output stage.

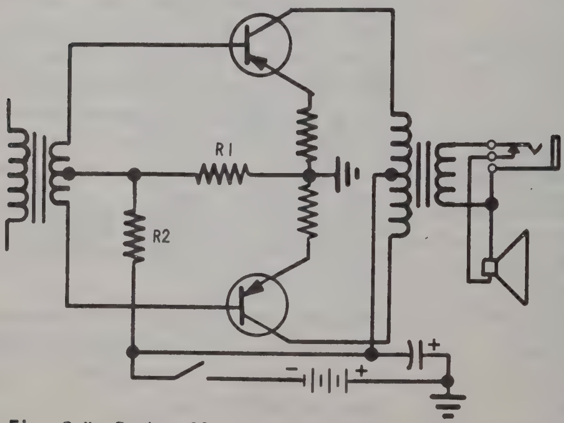


Fig. 3-4. Push-pull transistor audio output stage. Servicing with the VOM follows the same technique used for the single-ended stage.

Table 3-IV Causes For Push-Pull Amplifier Troubles.

TROUBLE	VOM CHECK
No output.	Service in the same way as for a single-ended stage. If the set uses a PC board, conductors will be close to each other and components will be close together. Sometimes transistors are wired in with long leads. These are very flexible and can short to each other.
Squealing, motorboating, or oscillation.	Use a VOM to run a voltage check on the battery. Set must be turned on, volume control advanced. Remove capacitor shunting the battery (unsolder one lead). Notice if voltage, as indicated by VOM, increases slightly. If so, replace capacitor.
Distortion.	Resistance check R1 and R2 or else check voltage drops across these resistors. Distortion will result if forward bias is incorrect.

look for the same troubles plus a few more due to the additional tube or transistor (see Table 3-IV). In a push-pull stage it's possible for one transistor (or tube) to work harder than the other. You'll never hear the difference until one output falls considerably below the other—then the sound will be distorted. Wrong voltages, or voltages that are too low, or a weak transistor (tube) are common causes. Ideally, push-pull transistors or tubes should be replaced by matched pairs, but this is usually a dream, not a reality.

To check the operation of a push-pull stage, use resistance and/or voltage measurements, just as you would with a single-ended stage. Notice that we haven't mentioned current measurements, as yet, for good reason. Current measurements mean that you must open a circuit. This often means soldering and unsoldering, or at least "breaking" a printed-circuit connection, something you should avoid if you can make other meaningful and fairly conclusive tests first. There's still another reason. Very few current values are given on schematic diagrams. Without some idea of the normal current value, a measurement has little meaning.

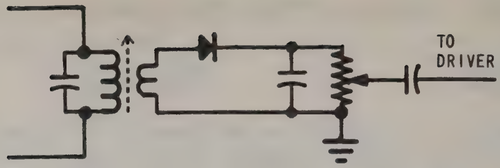


Fig. 3-5. Crystal diode detector stage. This stage is the only one in the receiver that does not rely on the battery supply for power.

The signal received by the audio output stage, whether single-ended or push-pull, usually is supplied from an audio amplifier or "driver" stage. Since it is simply an audio amplifier and since it usually consists of a single transistor or tube, we can check it in the same way as though it were a single-ended audio output stage.

The Detector

The detector in a receiver is simply a diode circuit, normally a semiconductor as shown in Fig. 3-5. Its job is to rectify a signal—eliminate one half of it (either positive or negative half). The output of the diode still contains both IF and audio frequencies. The filtering action of a single capacitor separates the two. The audio is sent along to the driver, while the IF signal is bypassed. Detector stage troubles which can be located with the help of a VOM are detailed in Table 3-V.

The AGC line supplies a bias voltage that counteracts the forward bias of one or more IF stages. It doesn't take too much bias voltage change to alter the operating characteristics of either transistors or tubes. AGC troubles usually result in distortion or no IF output. Generally, the signal sounds

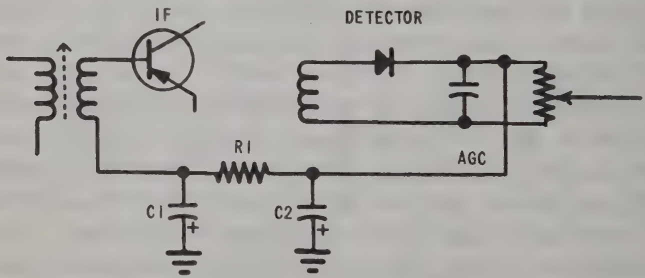


Fig. 3-6. This circuit shows the relationship between the detector and the AGC controlled IF stage.

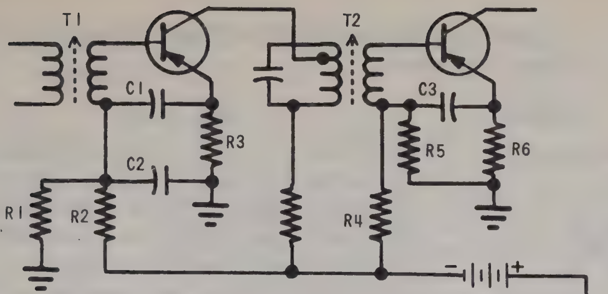


Fig. 3-7. Component troubles in IF stages can be located with the VOM.

good when weak, but distorts on strong stations. Resistance check R1 in Fig. 3-6.

The IF Section

The IF amplifier section is somewhat similar to the audio section, but there are enough differences to treat the IF section as a circuit in its own right (see Fig. 3-7). Table 3-VI details the sort of troubles commonly encountered in transistor receiver IF circuits and how a VOM can be used to find the causes.

The Front End

Transistor receivers use either an RF converter, or a mixer plus a separate local oscillator. The output, an IF signal, is the same in either case (see Fig. 3-8). If the oscillator does

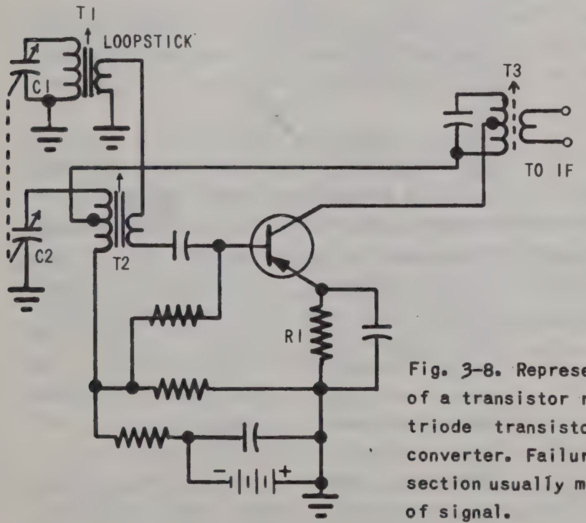


Fig. 3-8. Representative front end of a transistor receiver. A single triode transistor is used as the converter. Failure of the oscillator section usually means complete loss of signal.

Table 3-V. Detector Troubleshooting Chart (See Fig. 3-5).

TROUBLE	VOM CHECK
No output.	The diode in Fig. 3-5 does not depend on the battery or receiver power supply for voltage, so we can forget about these as far as no signal output is concerned. Resistance check the volume control. Connect a test lead to one terminal and the other test lead to the center terminal. Rotate the arm of the control. The meter pointer should move back and forward smoothly. Look for abrupt jumps or movement of needle pointer back to zero. Connect test leads across two outer terminals of the volume control. If meter pointer reads zero, replace control. Make sure you know what the resistance of the control is supposed to be. For transistor receivers, control may have a value of only 2,000 ohms. For tube receivers, control may be up to 0.1 megohm or more. Knowing value of control resistance will permit you to set the range selector on your VOM properly.
	Resistance check primary and secondary windings of last IF transformer.
	Disconnect one lead of the diode and make forward and reverse resistance checks. Look for a ratio of 100 to 1 or better.
	Capacitor shunted across volume control may be shorted. Disconnect one end and see what effect this has.
Weak signal.	Often due to misalignment or "screwdriver mechanic" adjustments. Connect VOM to read low AC volts across voice coil of speaker. Inject IF signal of proper frequency at input to stage preceding detector. Signal generator modulation turned on.
	Capacitor shunting the volume control may have too much capacitance. This sometimes happens when receiver is serviced and capacitor is replaced.

Table 3-VI. IF Troubleshooting Chart (See Fig. 3-7).

TROUBLE	VOM CHECK
No sound output.	Open circuit in one of the IF transformers, T1 and T2. Resistance test with set turned off. Note that T2 is a 5-terminal transformer, while T1 has 4 terminals. If any of the base bypass capacitors (C1, C2, or C3) are shorted, signal will be killed. Resistance check these capacitors. Disconnect one lead of capacitors when checking. Don't assume batteries are in place correctly. They may have been removed or inserted incorrectly. If batteries haven't been replaced for a long time, look for evidence of corrosion at battery connecting points. Resistance or voltage check biasing resistors.
Distortion.	If stage is AGC controlled (those shown in Fig. 3-7 are not) measure AGC voltage by setting VOM on low voltage scale and tuning in strong signals and weak signals. AGC voltage varies with location and receiver.

not work, the result will be no sound out of the receiver. If the oscillator injection voltage is low, the output level of the speaker will be low and weak stations may not be audible. Troubles in the loopstick (antenna) may also produce an odd condition in which no broadcast signals are picked up but the receiver sounds "alive" because of amplification of noise voltages. Table 3-VII outlines front-end troubles which can be isolated with a VOM.

While every possible receiver trouble has not been included in this Chapter, the information herein should give you a pretty good idea of how you can use a VOM in servicing. There are many other techniques, most of which you will learn

Table 3-VII. Front-end Troubleshooting Chart (See Fig. 3-8).

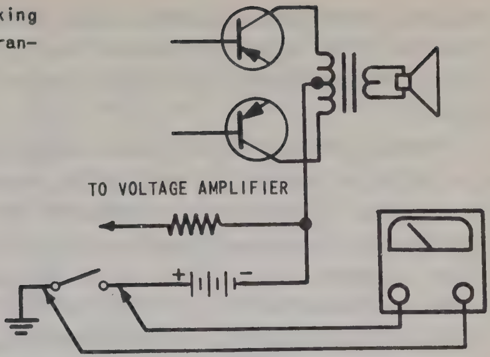
TROUBLE	VOM CHECK
No sound output.	If battery is ok, check local oscillator. Measure DC voltage across emitter resistor. Circuit shown in Fig. 3-8 uses PNP transistor so top end of R1 is minus, ground end is plus. Polarity is opposite for NPN.
Only single station can be picked up.	Check oscillator as mentioned above. If station is strong enough, receiver works somewhat like tuned radio frequency set.
Set sounds noisy when stations are tuned in, especially at low end of broadcast band.	Variable capacitor plates may be touching. Disconnect one wire from variable capacitor and make resistance check. Set VOM to read high ohms and connect one test prod to stator, other to rotor connection. Turn receiver dial while watching meter. Meter should read infinite resistance. If meter pointer flicks, rotor and stator plates are contacting.

through practical experience. As one example, if you are servicing a receiver with a constant complaint of intermittents, you can check the printed-circuit conductors by connecting your test leads across the conductor ends, setting the VOM to read resistance, and then gently flexing the printed-circuit board. You can use a VOM to check electrolytics. Set the VOM to read resistance, using one of the higher resistance ranges, and connect the test leads across the capacitor (connect red lead to positive end). The meter pointer will swing over to zero, then swing back toward the high resistance end of the scale as the capacitor charges. Of course, if the meter pointer moves over to the zero end and decides to stay somewhere in that vicinity, you need a new capacitor.

Current Measurements

Ordinarily, technicians avoid the use of the current-measuring section of the VOM since it means opening a circuit. There are times, however, when a current measurement is called

Fig. 3-9. Method for checking the current drawn by a transistor radio.



for. Fig. 3-9, for example, shows a method for checking a transistor radio that's as easy as making a voltage or resistance check. Set the function selector to DC current and the range switch to some value that will permit you to read the current to be measured so the meter pointer is near the right-hand side of the scale.

Manufacturers, in their circuit diagrams of transistor radios, sometimes supply data on battery current drain. In a typical receiver, for example, the total current drain is measured with the volume control set at minimum and with no signal input. The current drain under these conditions is usually quite small, in the order of a few milliamperes. To make the test, just connect the meter test leads across the switch, but keep the switch in its open position. If, for any reason, the current drain is substantially above that specified by the manufacturer, you have a shorted or a leaky component somewhere. In transistor receivers one or more high-capacitance electrolytics are shunted across the B-plus line. A leaky unit will increase current drain. Measuring total current in a battery-operated transistor receiver is easy, since

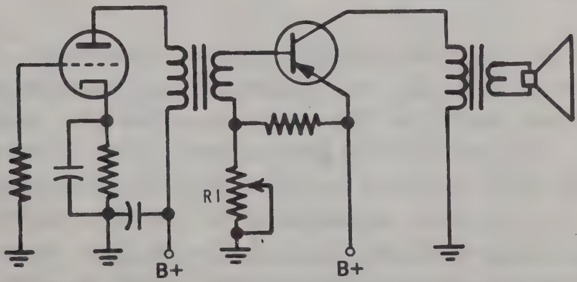


Fig. 3-10. Method for setting output stage current.

you can shunt the test leads of your VOM across the switch as shown in Fig. 3-9, or you can simply lift the snap-on connections to the battery. No soldering or unsoldering is necessary.

In some transistor receivers, especially auto radios, there is a variable control for setting the output transistor current. The amount of current to be taken by the transistor (if single-ended) or transistors (if push-pull) will be in the data supplied by the manufacturer. Fig. 3-10 shows R1 as this variable control. Disconnect the ground end of R1 and insert the meter leads. Before turning on the receiver, make sure the range selector on the VOM has been set high enough. The function selector should be on DC ma. Then adjust R1 until the meter reads the amount of current specified.

Why bother measuring current if it means connecting and disconnecting components? There is one advantage. A DC current measurement has very little effect on the circuit being checked. Since the meter is being connected in a series arrangement, the total current is the same throughout the circuit and the meter. There is no question about the impedance of the meter being high enough. It is true the meter does add some resistance to the circuit being checked, but this is usually a trifling amount. In some cases you will find it necessary to disconnect components to make resistance checks. As long as you have one lead of the component disconnected anyway, it is no great problem to set your VOM on its DC current function to check current flow. Some technicians have a prejudice against current measurements since they are in the habit of making voltage and resistance checks only. But if you keep an open mind about it, you may find opportunities for making current tests that will be both easy and useful.

Tube Current Measurements

Most of us like to think of tube current as a single current. No such thing. Actually, the current flowing through a pentode, such as that shown in Fig. 3-11, consists of a number of currents. We have screen grid current, plate, control grid current (if the grid draws current), and cathode current. The cathode current is the sum total of all the other currents, so the only way in which you can measure the total current is by opening the connection to the cathode circuit and inserting a VOM in series with it. Set the VOM to a suitable range, with

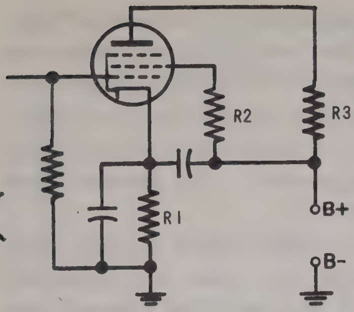


Fig. 3-11. In a pentode tube circuit, the cathode current is the sum of all tube currents—plate, screen grid, and a small control grid current.

the function selector set to read DC ma. You don't want any signal input to the tube since you wish to read a steady value of current. You can put the meter in series with the cathode either at the cathode end or the ground end of R1—it makes no difference.

If you want to measure the plate current, open the connecting lead to the plate. To measure the screen-grid current, open the connecting lead to the screen.

In the circuit of Fig. 3-12, a few electrons will manage to strike the control grid, even though it is biased negatively. These electrons will straggle down through the grid return resistor and will constitute some form of grid current. But you won't be able to measure it with your VOM because it will be too small. In certain circuits, such as oscillators, the grid does draw current which you should be able to measure. The control grid also draws current in test instruments such as a grid-dip meter.

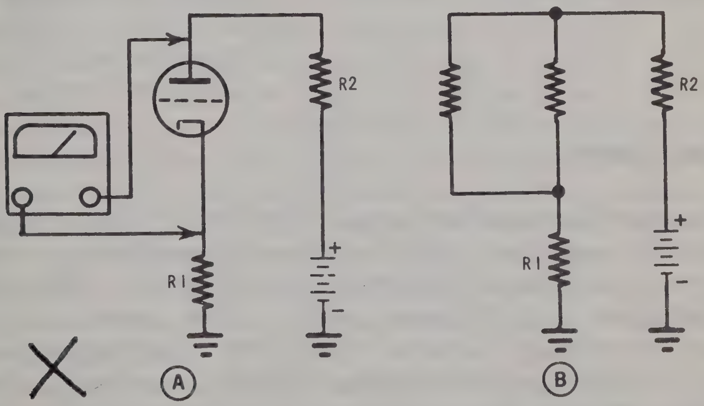


Fig. 3-12. In making voltage measurements, the VOM acts as a shunt load. Whether this effect will be serious depends on the amount of current shunted away from the tube by the VOM.

Batteries are a common cause of difficulty in transistor sets. Making a voltage check of the batteries isn't always conclusive. If you know the current requirements of the transistor receiver, a current check, with the VOM in series with the battery and with the receiver turned on, will soon tell you if the batteries are capable of delivering current. The current drop will be sharp and decisive.

Quite often a manufacturer will supply useful current data about his line of receivers. While this data is helpful for servicing, it is often ignored. If you know the current requirements of each stage of a receiver, making current checks of individual stages may sometimes be the fastest and best way of localizing difficulties. Here is some information about a typical transistor set:

Converter	-	average about 0.5 ma
First IF	-	average about 0.5 ma, with no signal
Second IF	-	average about 1 ma (with signal)
Audio preamplifier or driver	-	about 2 ma
Class B amplifier	-	Idling current should be less than 5 ma. This will rise to about 40 ma or more with signal

Circuit Loading

It sounds almost silly to say it, but not all VOMs are alike. If you are out to buy a VOM, get one having a high input impedance, at least 20,000 ohms-per-volt for DC. VOMs are available up to 100,000 ohms-per-volt. How important is the input impedance? It depends on the circuit you want to check. Fig. 3-12A shows a VOM being used to measure the plate voltage of a tube. As you can see, the meter is shunted right across the tube. What effect will this have? Fig. 3-12B shows the tube and meter represented by a pair of resistors

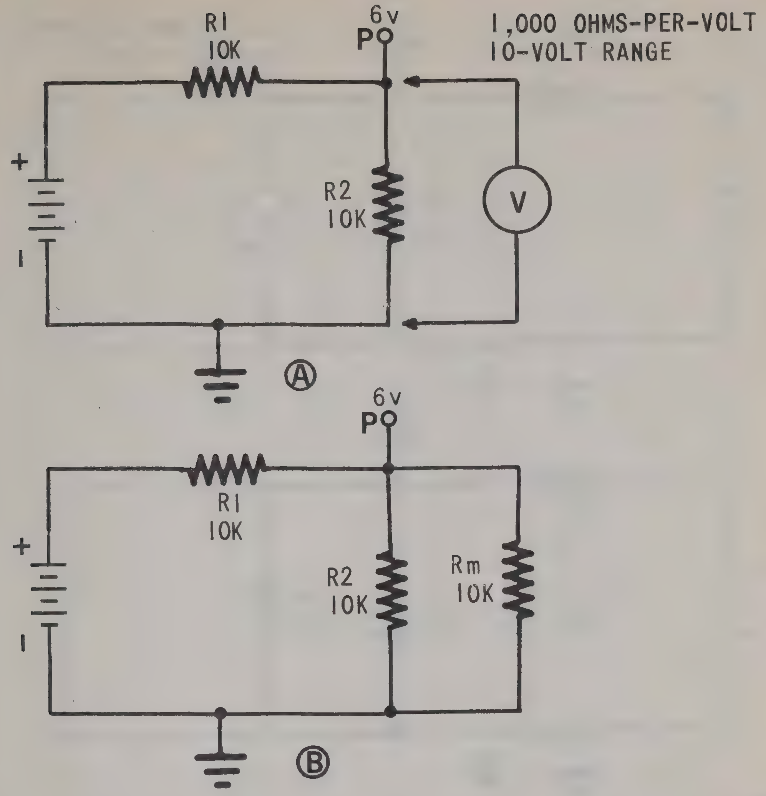


Fig. 3-13. Diagram showing the effect of a low-sensitivity voltmeter. НЭ/КАКОВОЛА Я

in parallel. In making the plate-to-cathode measurement, the meter reduces the total resistance in the circuit. As a result, more current will flow through R1 and R2, which means the voltage drop across them will be greater than the meter disconnected. But what about the voltage between plate and cathode of the tube? Since the sum of the voltage drops across R1, R2, and the tube must be equal to the battery or supply voltage, the voltage across the tube will decrease. But that is exactly what we are trying to measure. But how much will the plate voltage decrease? That depends on the impedance of the VOM. The higher its impedance, the smaller its shunting effect. OK-

И

МАМ

To understand the effects of circuit loading, refer to Fig. 3-13A. For the values shown, the voltage between point P and ground should be half the battery voltage—6v. If a 1,000 ohms-per-volt meter set on the 10-volt range was used to

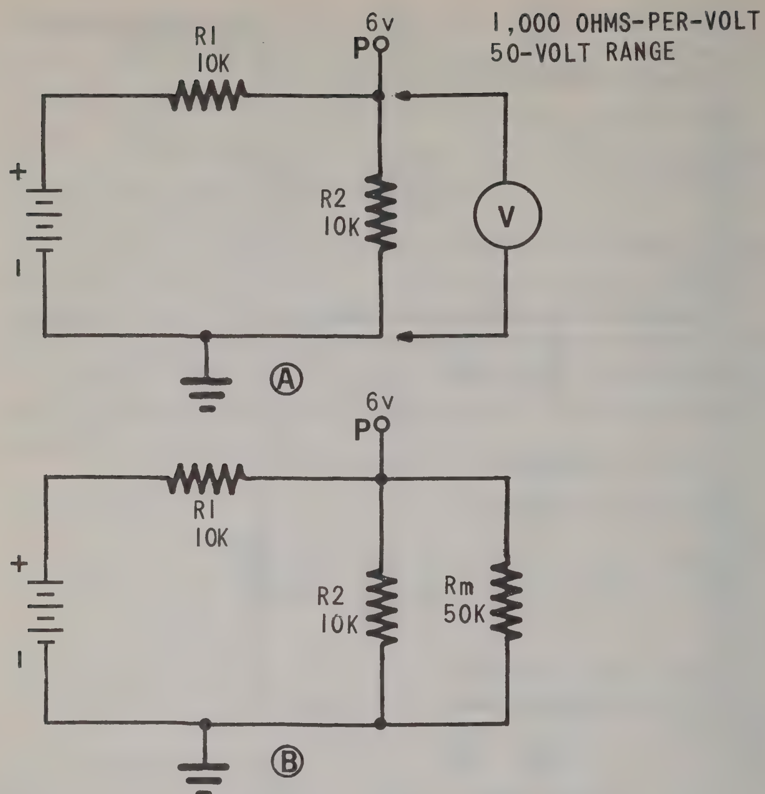


Fig. 3-14. A higher VOM range results in reduced circuit loading as shown here.

measure this voltage, the circuit is no longer like that at A, but is like that shown at B. Notice that Rm, the 10K meter resistance (1,000 ohms-per-volt on the 10-volt scale), is in parallel with R2, which is also 10K. The resultant resistance is 5K, the effective resistance in series with R1, and the voltage from point P ground is no longer half the battery voltage, but is now 4v. ?

The effects of loading can be reduced by using a higher range than that actually required. This makes it more difficult to read the meter accurately because the needle is deflected only a small amount. However, the higher range increases the meter resistance and reduces the loading. In Fig. 3-14A the voltage is measured between point P and ground with a 1,000 ohms-per-volt meter, but the 50-volt range is used. As shown in B the meter resistance Rm is now 50K, and this

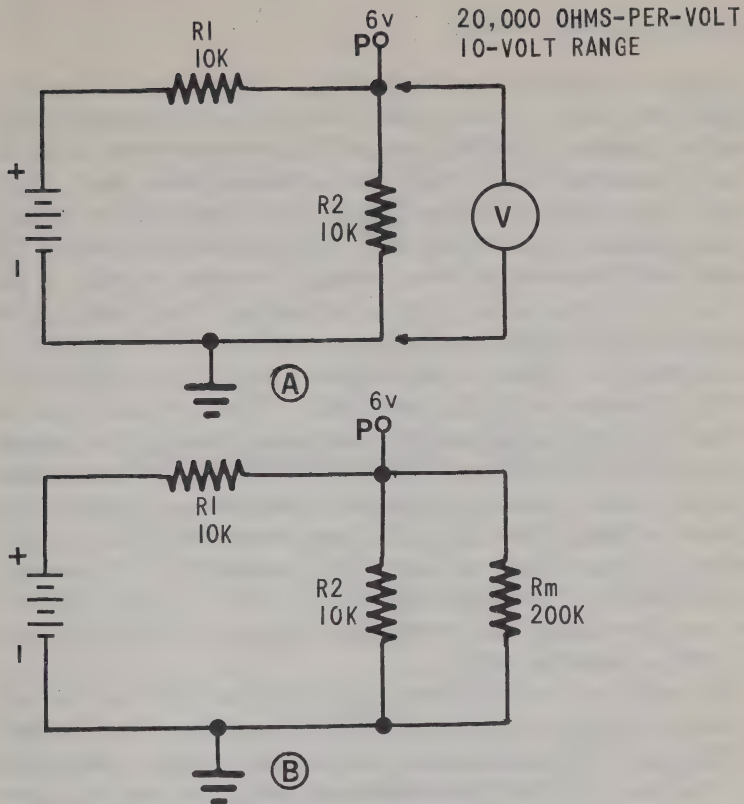


Fig. 3-15. Diagram showing how a sensitive voltmeter minimizes the effect of circuit loading.

value combined with R1 results in an effective resistance of 8,333 ohms. The voltage reading is 5.1 volts, which means that the difference caused by the meter is much lower than that caused in Fig. 3-13. While the difference is too high for most applications, it shows that switching to a higher range can reduce the effect of circuit loading.

Fig. 3-15 shows how a more sensitive voltmeter minimizes the effect circuit loading, since it requires less current for its operation. The voltage measured at point P and ground with a 20,000 ohms-per-volt meter indicates only slightly less than the applied voltage, 5.8 volts. With the voltmeter set on the 10-volt scale, Rm is 200,000 ohms in parallel with R2, resulting in an effective resistance of 9,524 ohms. OK

Capacitive Circuit Loading

Similar in effect to meter loading, capacitive loading of a circuit is caused by the test leads of the instrument being used to measure DC voltage when RF is present—for example, when measuring the grid bias on a local oscillator. Such loading is most noticeable when the test leads are effectively connected across a tuned circuit. The capacitance between the meter test leads can be large enough to cause detuning of the circuit. To minimize this type of loading, the circuit under test should be isolated as much as possible. This may be accomplished by adding a high-value resistor (usually 10K to 100K) in series with the test leads. The resistor may be clipped or wrapped around the test prod. Although the voltage indicated by the meter will be influenced by the divider action of the isolation resistor and the meter resistance, the presence of bias voltage at the grid of a low-power oscillator is sufficient evidence that the circuit is oscillating. Of course, when making such measurements it is better—and a greater degree of accuracy may be obtained—to use a VTVM (see Part II) with an isolation probe.

The next section describes the VTVM and how you can use it most effectively. For many of the tests described, either a VOM or VTVM can be used, but whether either instrument can be used for the same test will be determined by three factors: (1) the kind of VOM you have; (2) the circuit to be checked; (3) your understanding of what the circuit can tolerate in the way of loading by an instrument.

ХОРОШО

PART II

THE VACUUM TUBE VOLTMETER

How It Works

How To Use It

Servicing With the VTVM

CHAPTER 4

TYPICAL SENSITIVITY

How a VTVM Works

11MΩ

The information you get from a VTVM—by reading the position of a pointer on a scale—may be the truth or may be completely misleading. You cannot, with assurance, connect a test instrument across a circuit and expect to get completely accurate information unless you know how your instrument works, unless you know its limitations and, equally important, unless you know exactly what you are doing. Ideally, an instrument should have little effect on the circuit being checked. The vacuum-tube voltmeter (VTVM) fits this requirement because of its high input impedance, measured in megohms. Yet, for all its capability, the VTVM is a simple instrument. The principle complexity lies in its switching circuitry.

A typical VTVM is similar in many ways to the VOM. The principle difference is that it takes advantage of the amplifying properties of a tube or transistor. Thus, the VTVM is given a measure of responsiveness to small currents it could not possibly have otherwise. The VTVM can be used to measure AC and DC voltages, current, and resistance. But since these functions can also be performed by the usually less expensive and simpler VOM, why bother with a VTVM? There is a double answer to this question. The measurement range of the VTVM is much greater than that of a VOM. A representative VTVM would be able to measure up to 1,500 volts DC or AC, make resistance checks up to thousands of megohms, and could have a current range from milliamperes to amperes. Also, the input impedance, typically 11 megohms, is constant over the entire DC voltage range.

The Basic VTVM

Before we start examining the various circuits of a VTVM let's get an overall picture (see Fig. 4-1). The heart of the

VTVM is a meter. This could be an ordinary 0-1 ma movement, requiring 1 milliampere of direct current for full-scale deflection. Such a meter movement, by itself, has a sensitivity of 1,000 ohms-per-volt. The arrangement in Fig. 4-1 will permit three different types of input: AC volts, DC volts, and ohms. Not shown is the possibility of a current-measuring input. Following each input is a divider network. These are resistive circuits which act as "reducers" to limit the amount of input fed to the measurement circuit. The divider networks are adjustable by means of the range selector on the front panel of the instrument.

Following the divider networks is the switching circuit used to select particular functions. On the front panel this control is labeled function or selector, or function selector. This

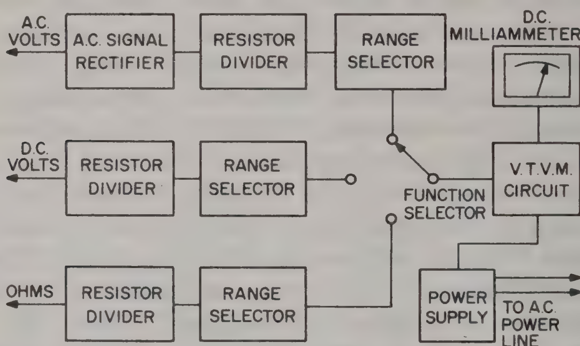


Fig. 4-1. Block diagram of a basic VTVM.

is the first control to be set when operating the VTVM. The next step is to set the range selector control. It is best to set this to its maximum position and then rotate it to some lower range until the meter pointer moves to about the center scale. From the function selector, the input is fed into a semiconductor or tube circuit which receives its operating power from an internal power supply.

DC Voltage Range Selector

The block diagram of Fig. 4-1 shows us that the basic idea of a VTVM is quite simple. With it we can "sample" some type of input, whether voltage or resistance (or current), and select the amount we want to measure by means of a range control. The function selector allows us to choose the kind of

input we want to measure. Now that we have this overall view, let's examine some of the circuit details, starting with the DC voltage divider.

Fig. 4-2 is a circuit diagram of a voltage divider network. The DC probe is a separate unit and consists of a 1 megohm Ω resistor built into a shielded housing. If your VTVM comes supplied with a probe for DC voltage measurements, it should be used, since calibration of the meter scale is based on the probe as part of the divider network.

Now let's see how this circuit works. With the DC probe connected and the function selector set to read DC volts, the divider network of Fig. 4-2 is active, while the dividers for AC and resistance measurements are inactive. Notice that

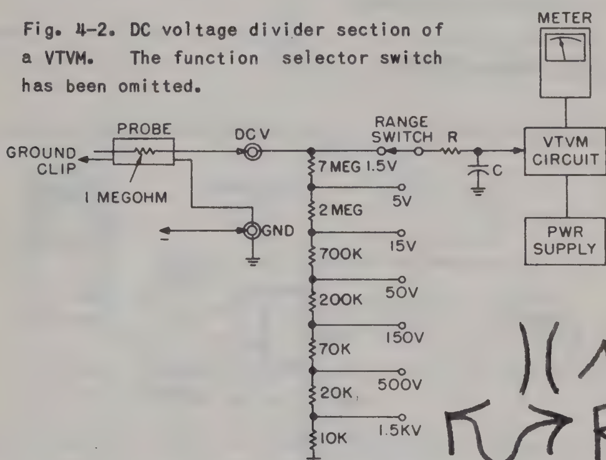


Fig. 4-2. DC voltage divider section of a VTVM. The function selector switch has been omitted.

MΩ

Rt

the DC voltage to be measured is applied across the entire resistance network, including the test probe. Thus, the input impedance is always the same, regardless of the range selected. The total here is 11 megohms. Some VTVMs have an input resistance of 25 megohms. The higher the voltage, the greater the amount of divider resistance required. Thus, by proper setting of the range switch the amount of voltage fed into the VTVM circuit will always be within set limits, regardless of the actual magnitude of the voltage at the probe tip. The R-C filter following the voltage divider, consisting of a resistor and a capacitor, acts to bypass AC voltages which may exist at the DC voltage points being checked.

Without the probe, the input impedance of the VTVM of Fig. 4-2 is 10 megohms. Since this impedance is far higher than

Yes

that of most VOMs, why bother with a probe? There are several reasons. If we used ordinary covered wire for test leads, instead of the probe, we might pick up some stray magnetic fields. This could induce a voltage across the test leads, producing an inaccurate meter reading. This problem is eliminated with the probe since it, and its connecting cable, is shielded. Using shielded wire, though, introduces a problem of its own: The capacitance of the shielded wire may detune circuits being checked, and this in turn could affect the DC voltage measurement. The 1 megohm resistance in the probe acts to isolate the capacitance of the connecting cable from the circuit being checked. For this reason the probe is often referred to as an isolation probe. Of course, it is also called a DC probe.

DC Voltage Measurement

Fig. 4-3 shows the VTVM being used to measure the voltage

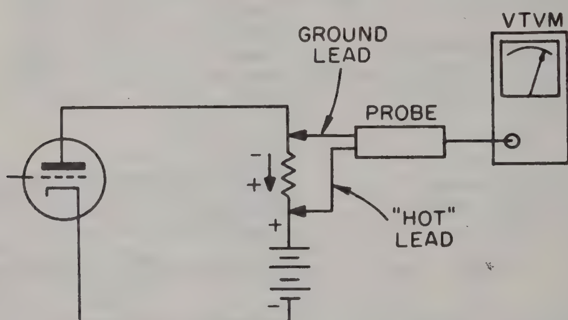


Fig. 4-3. The polarity of the voltage across the load is determined by the direction of the current flowing through it.

drop across a resistor. The arrow indicates the direction of current flow and we can see that the movement of current is such that the bottom end of the resistor is positive in polarity with respect to the top end.

Now this creates a minor problem. With the test probe connected as shown the current through the divider network will flow in the "negative" direction. This means the meter pointer, instead of moving up-scale, will move toward the left. There are two ways to meet this situation. We can transpose (Fig. 4-4) the test probes; however, most VTVMs have a plus-minus control on the front panel which gives the same result.

Thus, in making DC voltage measurements with a VTVM we must first concern ourselves with the things we must do before making any checks:

1. Set the function selector to its proper position—that is, set it to the DC volts position.
2. Set the range selector to its proper position. The safest procedure is to set this control to its maximum voltage position.
3. Decide whether the voltage we are going to check is plus or minus. This is easy to do if we know the direction of current flow (from minus to plus). ?

Loading Effect

Whenever a VTVM or VOM is used to measure voltage, the instrument "takes" a small amount of current away from the

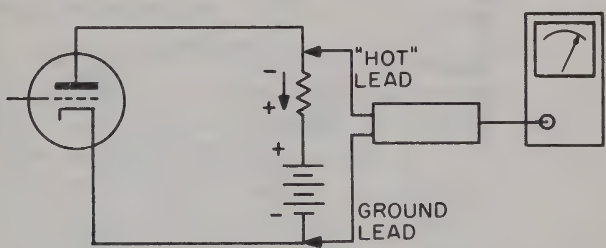


Fig. 4-4. It is important to know the polarity of the DC voltage before making a test.

circuit being checked. But any component or instrument that requires current acts as a load on the circuit being checked. The more current required by the test instrument, the greater is its loading effect. Whether this is serious or not depends on the ratio of the amount of current being "borrowed" versus the total amount of current available. It is generally desirable to load the circuit being tested as little as possible. The VTVM meets this requirement for just about all service functions.

Fig. 4-5 shows that the VTVM, with the function selector set to measure DC voltage, does draw current from the circuit being checked. Although the meter used in the VTVM might require as much as 1 milliampere for full-scale deflection, the amount of current passing through the high-resistance voltage divider is usually in the order of microamperes.

If we now set the function selector of the VTVM to read resistance, we will be using the circuit shown in Fig. 4-6. This circuit resembles that in Fig. 4-2, but there are some differences. In making DC voltage measurements, it is necessary that the circuit be checked in its "live" condition. But in making resistance checks, the circuit being tested must have

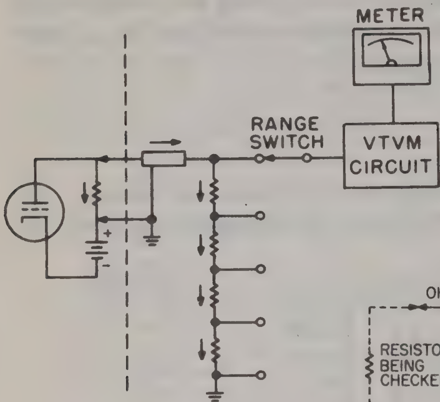


Fig. 4-5. The VTVM loads the circuit being checked since it takes away some of the current. The arrows show the direction of current flow through the voltage divider in the VTVM.

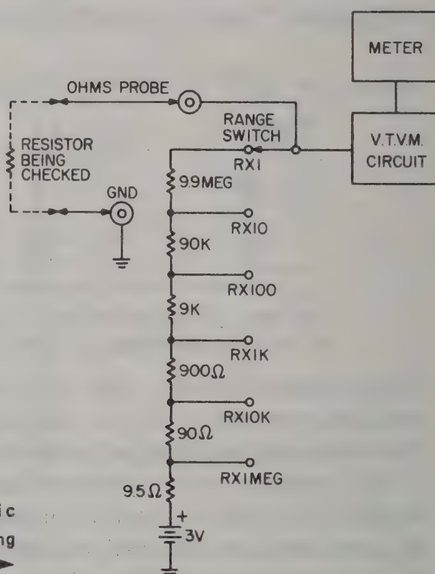


Fig. 4-6. Divider network schematic for a VTVM resistance-measuring section. →

its power off. How, then, do we obtain the power for making resistance checks? This is supplied, as shown in Fig. 4-6, by a small battery. We are using a 3-volt source here, but some VTVMs use only 1.5 volts. Basically, though, the idea is the same as that in Fig. 4-2. We are going to send a current through the divider network, using voltage supplied by a battery inside the VTVM instead of from the circuit being checked.

To understand the operation of the divider of Fig. 4-6, let

us suppose that we have not as yet connected a resistor across the test leads. Since there is no return path for the current, there is no current flow. If we now connect the test leads across a resistor, current will flow from the negative terminal of the battery, through the resistor being tested and the divider network to the positive terminal of the battery. Thus, a voltage drop is produced across the divider network. It is this voltage drop that is used in making the measurement, and not the actual value of the resistor. That is why the circuit of Fig. 4-6 so closely resembles that of Fig. 4-2. Essentially, they both work the same way. At this time, though, we read resistance on our meter scales. The resistance scale of the meter is calibrated using Ohm's law as a basis. If we know voltage and current, it is no great difficulty to calculate resistance.

AC Voltage Measurement

Whether or not we can measure the actual value of an AC voltage depends on its waveshape and frequency. While the meter may indicate the presence of voltage, the indication many have no further meaning—that is, the reading may be completely incorrect and misleading unless we know something about the design of the particular instrument, its limitations, and the shape of the voltage wave to be measured.

An AC voltage can have almost any waveshape. Those shown in Fig. 4-7 are symmetrical—that is, the positive and negative portions are the same. Generally speaking, a VTVM will measure such AC voltages with a fair amount of accuracy, particularly when they are pure sine waves. Usually, VTVMs are designed to measure either rms or peak-to-peak values. The peak-to-peak value is the difference in level between the positive and negative peaks. The rms value is approximately 70% of the peak value (between one peak and zero level). Fig. 4-8 shows the difference between rms and peak-to-peak. If your instrument is the type that is calibrated in rms values, you can calculate the peak-to-peak voltage by multiplying rms readings by 2.83.

Fig. 4-9 shows a simple divider network used for measuring AC. The AC voltage is passed through a rectifier, then applied to a resistive divider network of the same type used to make resistance and DC voltage measurements. The DC current at the output of the rectifier flows through the divider and

2.83 X RMS = PEAK TO PEAK

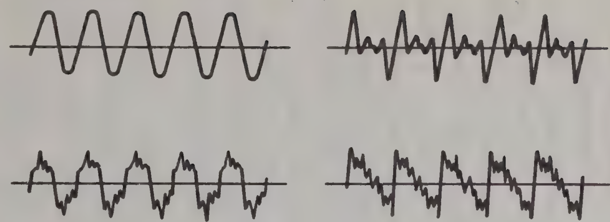


Fig. 4-7. These are some types of AC waveforms encountered in electronics.

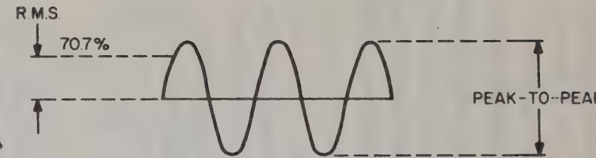


Fig. 4-8. Drawing showing peak-to-peak and rms values of a sine wave.

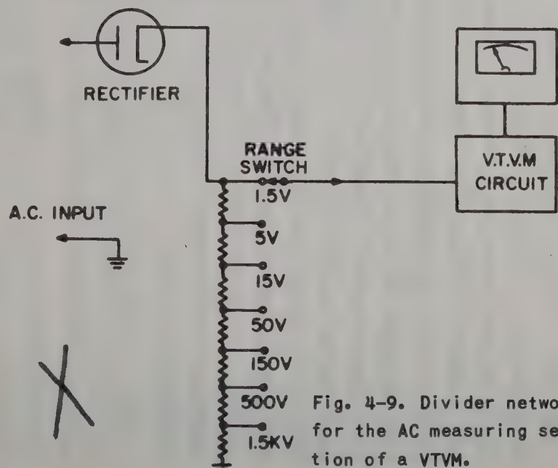


Fig. 4-9. Divider network for the AC measuring section of a VTVM.

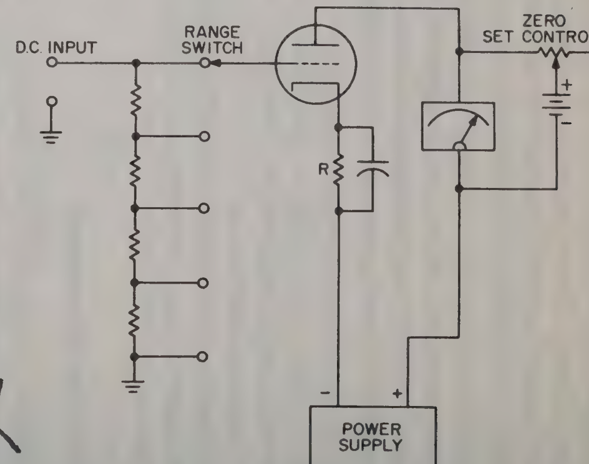


Fig. 4-10. Simple triode amplifier VTVM circuit.

the resulting DC voltage is measured. For peak-to-peak measurements, a dual diode circuit such as described in Chapter 1 is used, providing DC current pulses for each half cycle of the input AC voltage.

VTVM Circuit

The VTVM circuit receives the same type of input no matter what the position of the function selector—a DC voltage. This is a distinct advantage because the same input circuit can be used for measuring resistance or DC and AC voltages. No matter what we measure, we can regard that input as a signal.

Fig. 4-10 shows a basic VTVM circuit. By taking advantage of the amplifying properties of a tube or a transistor, we can use a small signal input to give us a large signal output. Assume for the moment that the instrument is set up but not connected to make any measurements. The positive voltage on the plate of the tube, furnished by the power supply, will cause

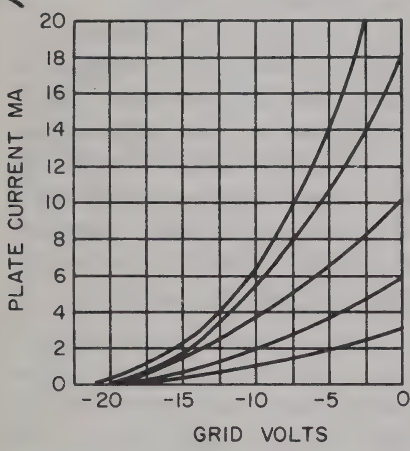


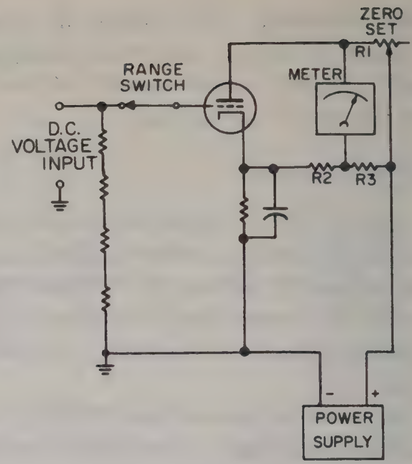
Fig. 4-11. Transfer characteristic curves for a triode.

MUTUAL CHARACTERISTICS KURVES

current to flow through the meter, thus causing the meter pointer to move forward. To counteract this, a voltage is placed across the meter. This voltage tries to force a current through the meter in opposition to the plate current of the tube. Thus, with the help of a variable resistor called a zero-set control, the meter movement can be made to read zero.

To understand what is happening we must consider the transfer characteristics of a vacuum tube. The family of curves in Fig. 4-11 (also known as mutual-characteristic curves) are

Fig. 4-12. VTVM using a bridge circuit to obtain zero-setting meter action.



for a triode. These curves are a plot of grid voltage versus plate current, showing the effect grid voltage has on plate current. In a VTVM the grid voltage is the "signal" voltage or the "sampling" voltage picked up by the test leads.

The disadvantage of the circuit in Fig. 4-10 is that it requires a separate voltage source to zero-set the meter. We can eliminate the battery by using the VTVM circuit in Fig. 4-12. To understand how this circuit works, let us first consider the bridge circuit in Fig. 4-13. The circuit consists of resistors R1, R2, R3, and R4, plus a voltage source and a meter. Current will flow through the meter only when point A is at a higher potential than point B. If A and B are at the same voltage, current will not flow through the meter. To

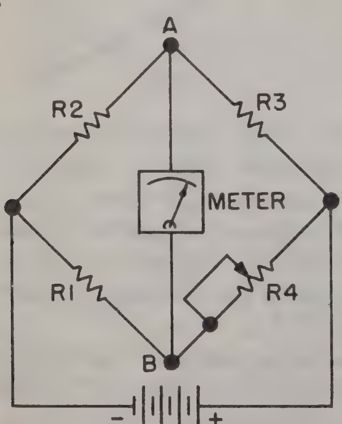


Fig. 4-13. When this bridge is balanced, current does not flow through the meter.

balance the bridge—that is, to arrive at a null point or zero-current point—one of the resistors, which could be called a zero-set control, is made variable.

When current leaves the negative battery terminal, it will divide at the junction of R1 and R2, and the divided current will continue—some of it flowing through R3 and some through R4. The current reunites again at the junction of R3 and R4 and returns to the battery. In flowing through the resistors the current produces a voltage drop across each of them. If the voltage at point A is exactly equal to that at point B, current will not flow through the meter, since there can be a current flow only when a difference of potential exists. By adjusting R4 the voltage at point A can be made exactly equal to that at point B.

In Fig. 4-12 the bridge consists of R1 (zero-set control),

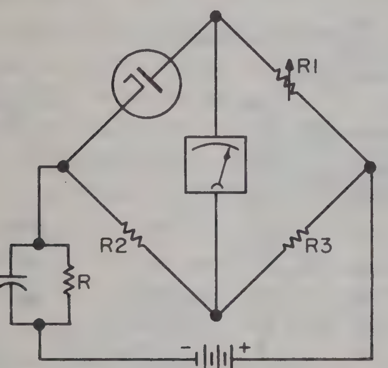


Fig. 4-14. The circuit of Fig. 4-12 rearranged to show bridge configuration.

R2, R3, and the cathode-to-plate resistance of the tube. This bridge arrangement is redrawn in Fig. 4-14; the cathode resistor and its bypass capacitor have not been included, but since these components are external to the bridge and in series with it, they do not affect bridge action. Thus, considering the VTVM circuit in Fig. 4-12, we can still zero-set the meter. In all other respects, though, the action of the circuit is the same as that in Fig. 4-10.

? Yes

While VTVM circuit of Fig. 4-12 eliminates the difficulty of having a separate battery for zero-setting, it also has some problems of its own. One is a tendency to drift. After the meter has been zero set, it would be nice to assume that the pointer will remain on zero. However, if the instrument is used for any length of time there is a tendency for the pointer to move away from zero. This is particularly true when shift-

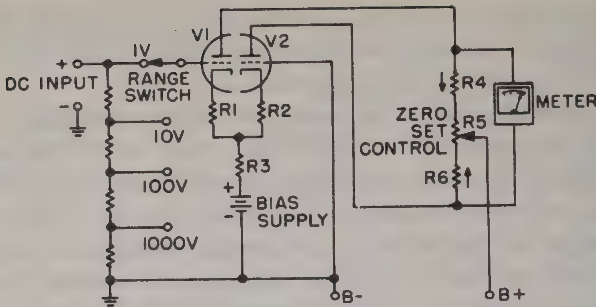
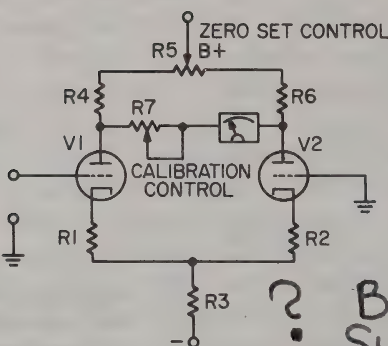


Fig. 4-15. Dual balanced-triode circuit. R5 is the zero-set potentiometer.



? BIAS SUPPLY IS + in 4-15 ?

Fig. 4-16. This simplified circuit of Fig. 4-15 shows the bridge arrangement.

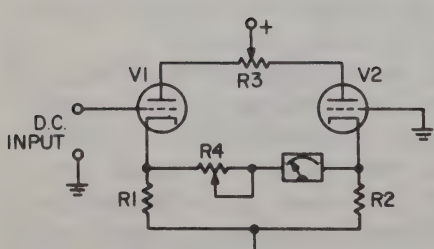


Fig. 4-17. A VTVM bridge with the meter in the cathode circuit.

ing the range switch. Consequently, with VTVMs using the circuit of Fig. 4-12, it is necessary to adjust the zero-set control fairly often.

The balanced circuit, using a dual triode shown in Fig. 4-15, eliminates this difficulty. The first triode section serves as amplifier just as in the previous circuit. The second half of the triode is actually part of the meter circuit itself. In the absence of a signal—that is, with no DC voltage input—both tubes, V1 and V2, draw about the same amount of current. The control grid of V1 is connected to the resistor divider network. When there is no current flowing through this network, the control grid of V1 is effectively connected to the B-minus bus, as is the grid of V2. Current will flow through both triodes, and with proper adjustment of R5 the voltage at the top end of R4 will be exactly equal to the voltage at the bottom end of R6. Thus, no current flows through the meter. This circuit is better than the one in Fig. 4-12 because any variation in line voltage or power supply will affect V1 and V2 equally. As a result, once R5 has been set to zero, changes will be cancelled and the meter pointer will remain on zero.

Let's assume the VTVM is connected to a DC voltage, putting a positive voltage on the control grid of V1, thereby causing its plate current to increase. This current will flow through R4 and part of R5, making the top end of R4 highly negative. The grid of V2 remains permanently connected to B minus, therefore, it does not receive any part of the input signal. The increased plate current of V1 also passes through R3 and helps supply part of the bias voltage for V2. As more current flows through R3, its top end becomes more positive. This makes the cathode of V2 more positive and at the same time the control grid of V2 more negative. But as the control grid of V2 becomes more negative, the current through that section decreases, and as a result there is less current flowing through R6 and part of R5. This makes the bottom end of R6 less negative or more positive. Now we have the top end of R4 at a more negative potential and the bottom end of R6 at a more positive potential, resulting in a difference of potential across the R4, R5, and R6 network. This voltage will drive a current through the meter.

Although it may not be obvious, the circuit of Fig. 4-15 is a bridge arrangement, as is apparent in Fig. 4-16. There is one difference, however; another variable resistor, R7,

has been added. This component is known as a calibration control and is an internal adjustment. In using the VTVM zero-set control, R5 is adjusted (with no DC voltage input to V1) until the meter pointer rests at zero. The test leads are then connected to a source of known voltage (for example, a fresh dry cell). R7 is then adjusted until the meter pointer reads this exact amount of voltage. Some VTVMs have separate calibrating controls for functions such as plus DC volts and minus DC volts. The calibration controls are mounted inside the instrument and usually have a slotted shaft to accommodate a small screwdriver. There is no calibration control for the resistance measuring section of the VTVM, but usually both

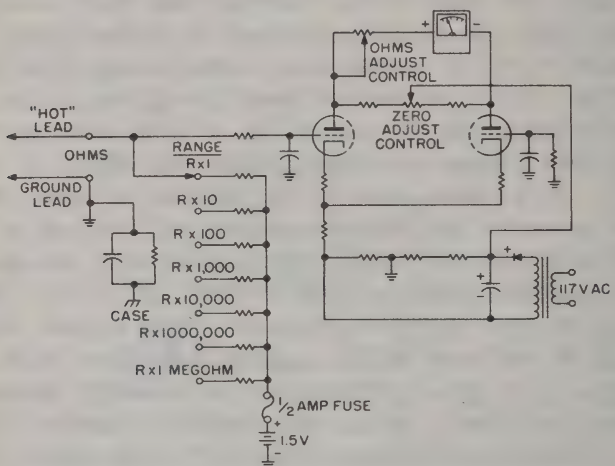


Fig. 4-18. Resistance-measuring circuits of a VTVM. The zero-adjust and ohms-adjust are front panel controls.

ohms-adjust and zero-adjust controls are provided as front panel adjustments.

Fig. 4-17 shows another type of bridge circuit with the indicating meter in the cathode circuit. The method of operation is exactly the same as in Fig. 4-16.

The Ohmmeter Section

Essentially, a VTVM can be considered as having three circuits which work together—a resistive divider circuit, a VTVM circuit (usually a bridge arrangement), and a power supply. Fig. 4-18 shows the resistance-measuring section of a VTVM. When the function selector is in its resistance posi-

tion, the components shown are the only ones in operation. A 1.5-volt cell drives a current through the resistor selected by the range switch. This current exists only when the input test leads are shorted or if a resistor (or other conductor) is placed across the input. The voltage or IR drop produced by this current, as it flows through one or more of the divider resistors, is applied to the control grid of the first triode. As a result, the bridge becomes unbalanced and current flows through the meter. The movement of the pointer will be proportional to the resistance being measured.

There are two controls of interest in the resistance-measuring section—the ohms-adjust and zero-adjust controls. Both are front panel controls. The zero-adjust control is set with the test leads shorted, producing full-scale deflection of the meter. The ohms-adjust control is set with no connection across the input, with the input open circuited.

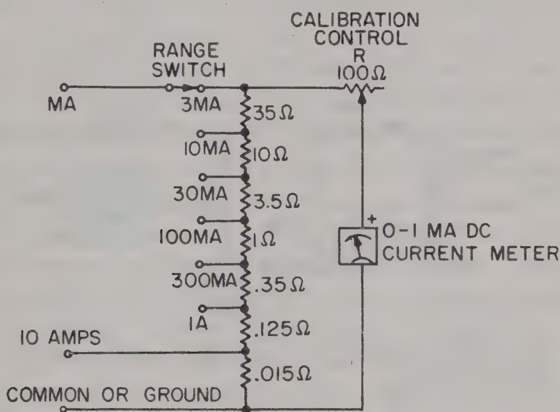


Fig. 4-19. The current measuring section (for DC only) is the simplest of all the circuits in the VTVM. The divider shown here is simply a shunt across the meter. Resistor R is an internal calibration control adjusted at the factory.

Current Measurements

Not all VTVMs have a current measuring feature. Those that do utilize shunt resistor circuits similar to those described in Chapter 1 for the VOM. If the current to be measured is substantial—in the order of amperes—it is important that the connections be secure and substantial, since poor contact

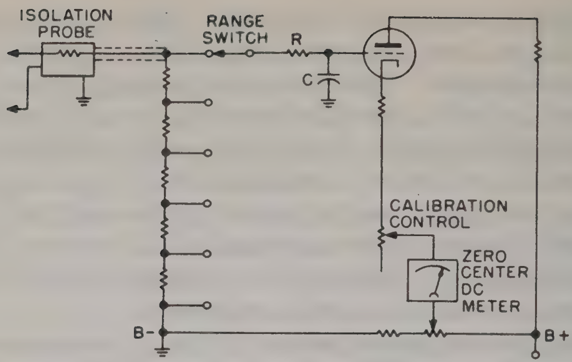


Fig. 4-20. A VTVM circuit using a zero-center DC milliammeter as an indicator.

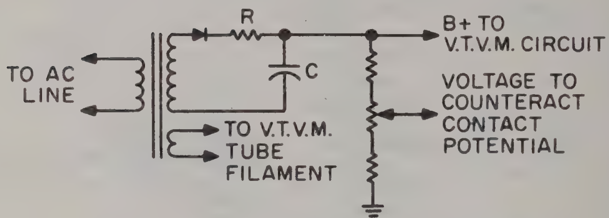


Fig. 4-21. A simple half-wave power supply using an R-C filter.

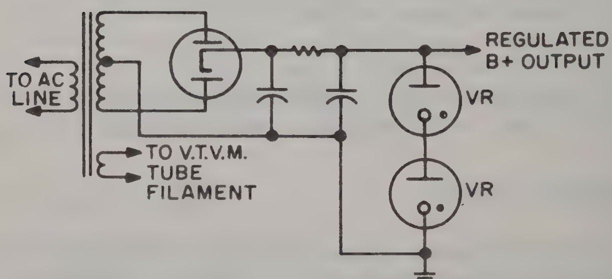


Fig. 4-22. A full-wave power supply with constant voltage output controlled by voltage regulator (VR) tubes.

means a high resistance at the connecting points. This can produce a voltage drop which will affect the readings. When measuring current, the bulk of the circuitry of the VTVM—such as the triode amplifier and the power supply—are completely omitted. As you can see in Fig. 4-19 all we have is the meter itself, plus a shunt divider network. In the voltage and resistance functions the current flowing through the divider section produces a voltage which acts as a signal or bias for a bridge-type triode amplifier. In Fig. 4-19, though, the divider is simply a shunt across the meter. Neither the internal power supply nor the battery used for measuring resistance are required.

It is interesting to note that in its current measuring function there is no true VTVM action—that is, we do not take advantage of the amplifying action of the tube or transistor amplifier section of the instrument. All the range selector does is to control the amount of shunt resistance across the meter. The least amount of resistance is placed across the meter when the range switch is in its maximum-current (10 amperes) position. Maximum current through the meter is 1 milliampere for this particular meter.

Notice that only DC current is to be measured. There is no provision for measuring alternating current. The current measuring circuit of the VTVM is the simplest of all the circuits in the VTVM, but for that reason it is perhaps the most vulnerable. If, for example, the range selector is set to read 3 ma when it should be at the 1 amp position, there is a good chance of meter burnout. The safest procedure, as in the case of voltage measurements, is always to keep the range switch set on its maximum position.

Zero-Center VTVM

Most service-type VTVMs are designed so that the voltage scales of the instrument start with zero on the left-hand side. Thus, when you touch the isolation probe to a negative voltage point when the instrument is set to read a positive voltage, the needle will go off scale. There are times when you want to use a meter to zero-adjust a circuit, such as a discriminator. The zero-center scale VTVM avoids this difficulty. In this instrument, zero is at the center of the meter scale. The disadvantage, of course, is that the effective length of the scale is cut in half. Unless a rather large meter face is

used, this tends to make the numbers and divisions on the meter scale somewhat cramped. Thus, a meter scale which would normally have a total length of 6 inches (in the form of a slight curve) would have a working length of only 3 inches when zero center is used.

Fig. 4-20 shows the basic circuit of a center-reading VTVM. This arrangement is for the DC voltage section of the instrument only. Notice that the meter is the same type described in connection with other VTVM circuits. The meter is connected in the cathode circuit of the triode. With no voltage input the meter reads a certain amount of current, depending in part on the setting of the wirewound calibration control. The calibration control can be set so that the meter pointer is at center scale.

If the voltage being checked by the test probe is negative, the voltage will be applied to the control grid of the triode through the resistor divider network. But a negative voltage will reduce the current through the tube. When this happens, the meter pointer will move away from its center position toward the left. If the voltage picked up by the test probe should happen to be positive, the meter pointer will move to the right of zero. Notice that in an instrument of this kind, current always flows through the meter, even in the absence of a DC input voltage. ? Battery drain ?

VTVM Power Supplies

The power supply for a VTVM may use either a semiconductor or vacuum-tube rectifier. Some of the supplies, such as the one shown in Fig. 4-21, are quite simple, using a half-wave rectifier. A small amount of positive voltage is tapped off the power supply bleeder. This voltage is used to counteract the effects of the contact potential of the diode rectifier used when the instrument is set to measure AC voltage. The disadvantage of this circuit is that the output voltage will change with fluctuations in the line voltage. It may also change when the range switch of the VTVM is rotated. Instruments using a power supply of this type may also require readjustment of the zero-set control each time the range switch is changed. In some test instruments a dual diode is used, one half as a rectifier in the power supply, the other half of the diode as an input signal-voltage rectifier when the function selector switch is set to read AC volts.

Fig. 4-22 shows a more elaborate supply used in better grade test instruments. A full-wave rectifier is used, plus an elaborate filter. In addition, gas-tube voltage regulators are used to maintain a constant DC supply voltage. The power supplies in some laboratory-type VTVMs are quite elaborate. The power supply may use a gate tube (for maintaining constant DC output) in addition to a gas-tube regulator. Also, there may be a power supply to furnish DC for the tube filaments.

Transistorized VTVM

Transistors can be used in VTVMs with the particular advantage that the instrument can be made independent of the AC power line. With transistors, and a small battery to supply

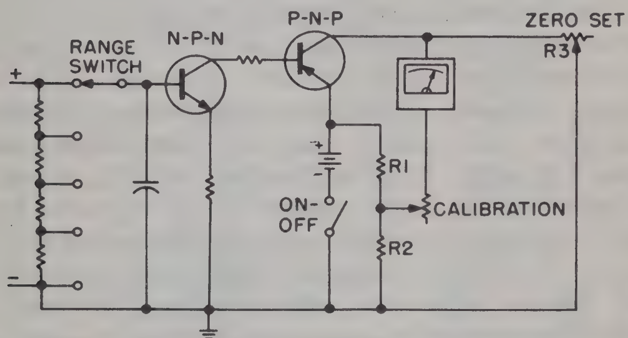


Fig. 4-23. Transistorized VTVM using a pair of direct-coupled transistors.

voltage, the VTVM can be made small enough and light enough to be truly portable. Fig. 4-23 shows the arrangement of a pair of transistors used in a VTVM for the measurement of DC voltages. At the input, as in a tube-type VTVM, we have the usual resistive voltage divider with values selected by the range switch. The DC voltage is fed to the base-emitter input of an NPN transistor. The current through the first transistor is determined by the amount of DC voltage applied. The output of this transistor is directly coupled to the following PNP stage. Amplification takes place in both transistors. The meter is connected into the familiar bridge-circuit arrangement, consisting of the emitter-to-collector resistance of the second transistor, resistors R1 and R2, and potentiometer R3. The meter, of course, is connected across the bridge.

CHAPTER 5

How to Use a VTVM

There are usually four controls on the front panel of a typical VTVM—function and range selectors, a zero-adjust control, and an ohms-adjust control. The front panel in the layout in Fig. 5-1 also shows the location of the test lead terminals and should help in identifying the controls and jacks on any VTVM. Before attempting measurements the VTVM should be allowed to warm up for a minute or two. When the power is first turned on, the meter pointer may swing to the right then drop back to zero. If it doesn't, rotate the zero-adjust control to position it at zero. When the function switch is turned to the ohms position, the meter pointer will swing to the far right (infinite resistance) and come to rest at the last division on the scale. If it doesn't, rotate the ohms-adjust control. Also, before making resistance measurements, the zero-adjust control should be used to make sure the pointer rests at zero (left) when the test lead tips are touched together. It shouldn't take more than one or two settings of the ohms-adjust and the zero-adjust controls to have the meter pointer rest at zero and infinity. But these controls do interact, and if you get adjustment at one end of the scale and not at the other, the instrument probably needs a new battery.

Precautions in Use

There are several precautions that should be observed in using a VTVM—precautions against dangers that may be lurking in equipment to be tested. There are certain electronic components that could possibly be damaged by the VTVM internal battery voltage during resistance measurements—thermocouples, tube filaments, and some semiconductors—even though the battery voltage is low. When the VTVM is not in use, rotate the function switch away from its resistance set-

ting so that the batteries aren't accidentally discharged. There is no drain on the battery when the meter is set to read volts.

It is important to use the right ohmmeter scale when measuring resistance or continuity. If a high range is used, a low-resistance part or a poor connection will show up as a full-scale or a closed-circuit reading. Use the high range only when checking high-resistance circuits. If a low range is used, a fairly high resistance will give the same reading as an open circuit. The resistance value will be known approximately, either by its markings or circuit information; therefore, the range that will give approximate half-scale indications should be used. Another precaution is to be sure that the fingers do not touch the ends of the test prods, because the resistance of the body will cause an inaccurate indication

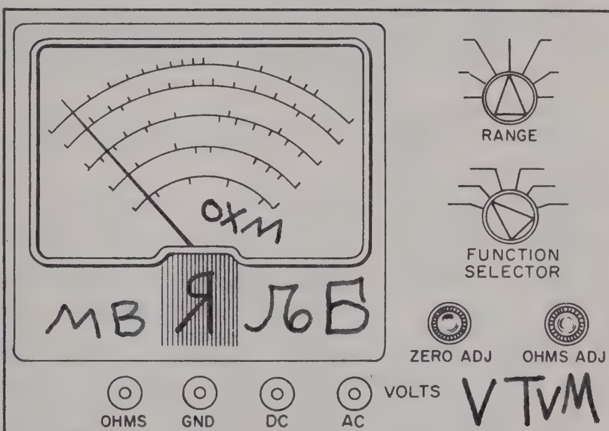


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Fig. 5-1. Typical VTVM front panel layout.

on the ohmmeter. Sometimes a resistor will have normal resistance when it is cold, but will change value as its temperature rises. Measure the voltage across it as soon as the power is turned on and also after it warms up. If the voltage changes considerably over a short period of time, the resistor may be changing in value and should be replaced.

In checking voltages on transformerless equipment, be especially careful about assuming that the metal chassis of the equipment is neutral or ground—it may have power line voltage on it. This would be the case in an AC-DC receiver with the plug in the outlet the "wrong" way. Attaching the "cold" or ground test lead to the receiver chassis may have the effect of putting full line voltage on the metal case of your instru-

ment. There are two ways to avoid this situation. Check for any AC voltage between the chassis and ground (a cold water pipe, etc.). If you measure any voltage the chassis is hot, and the line plug should be reversed in the socket. A better method, though, is to use an isolation transformer between the power line and the equipment under test.

? KaKo ?

DC Voltage Measurements

The circuit of Fig. 5-2 shows a pentode amplifier labeled with various test points. To measure the plate voltage (the voltage existing between the plate and the cathode), connect the ground clip of the isolation probe to the cathode (point B). With the function and range controls set to the highest DC voltage range, touch the probe tip to point A. To measure the screen grid voltage, the ground clip would remain at point B. The tip of the test probe would simply be moved to point

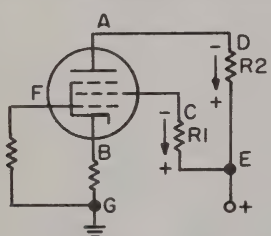


Fig. 5-2. Schematic showing DC voltage test points in a pentode tube circuit.

C. The voltage drop across the cathode resistor is often so small that most technicians, for the sake of convenience, connect the ground clip of the probe to the chassis (point G). If the screen and plate voltages are fairly high, 100 volts or more, and the drop across the cathode resistor is just a few volts, the small error is of little concern.

There are two ways of measuring the bias voltage—the DC voltage difference between control grid and cathode (between points F and B). There may be some current flowing through the resistor between the control grid and ground but this is generally so small it can be ignored. To measure the bias, connect the ground lead of the isolation probe to ground (point G) and touch the test probe tip to the cathode (point B). Or, you could connect the ground clip to point B and touch the probe tip to point F. In this case, the voltage is negative, so the polarity switch must be in the minus position. Either method is satisfactory, although the first is easier.

R1 is the screen dropping resistor and R2 is the plate load.

? Polarity Switch

The direction of current flow through these resistors is indicated by the arrows. This tells us the polarity of the voltage drops. To check the voltage across R1, connect the ground clip of the isolation probe to point C and then touch point E with the probe tip. To measure the voltage across R2, move the ground clip to point D and then touch point E once again with the probe tip. You also can measure the voltage drop across these two resistors with the ground clip connected at point E and the VTVM voltage polarity switch in the minus position.

These voltages are supposed to be DC. However, if the tube is amplifying a signal the AC modulation may have some effect on the measurement. The screen grid and cathode resistors are generally bypassed with capacitors, so the DC voltages at these elements should not be affected. The grid and plate voltage measurements will be altered, however. To avoid this, short the antenna to ground.

Testing Power Supply Voltages

Fig. 5-3 shows how to test a full-wave rectifier with a filter and a voltage divider. The maximum DC output voltage of this supply is between point A and ground. Connect the ground clip of the probe to the power supply chassis and touch point A with the probe tip. If you move the probe tip to point B you will read a slightly lower voltage due to the drop across the choke coil. The resistor network across the output of the power supply acts both as a voltage divider and as a bleeder (to discharge the filter capacitors). By touching the test probe to points C and D you can check the voltage drops across this voltage divider. The arrows indicate the direction of direct current flow. This makes the bottom (ground) end of the

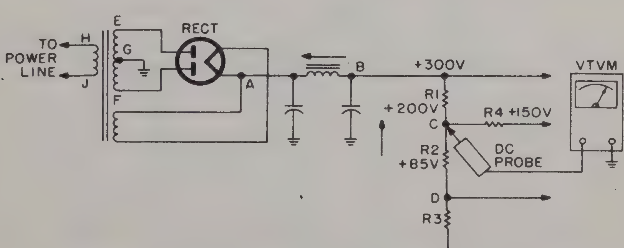


Fig. 5-3. AC and DC voltage test points are shown in this typical power supply schematic.

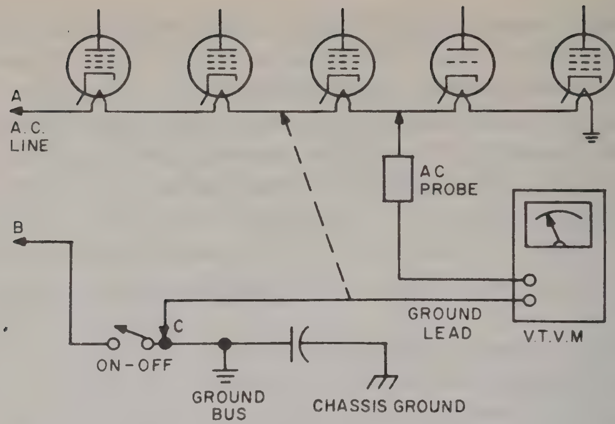


Fig. 5-4. Schematic showing AC voltage test points in a typical AC-DC receiver

divider negative with respect to the top. It also makes point B negative with respect to point A. We can measure the voltage drop across the filter choke by connecting the ground lead to point B and the probe tip to point A.

To measure AC voltages, rotate the function selector and set the range control to some high setting. Connect the ground lead to point G (or ground) and the other test lead to point E, then to point F. Each of these readings indicates the voltage of one half of the secondary winding. To determine the full voltage, multiply one reading by 2, or add the two readings. The input or primary voltage can be checked by connecting the

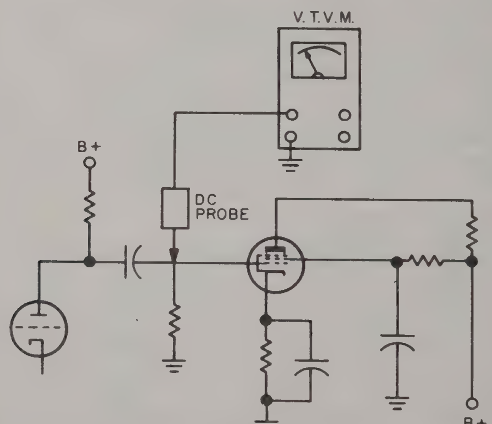


Fig. 5-5. A leaky or shorted coupling capacitor in a circuit such as this will apply a positive voltage to grid of the succeeding tube.

test leads across points H and J. Normally, this will be 110 to 120 volts rms.

Testing Filament Voltages

Since the filaments of the tubes used in AC-DC receivers are connected in series, a single open filament means that none of the tubes in the receiver will light. The problem then arises of isolating the defective tube. One method is to substitute tubes, one at a time, until the defective component is located. This method takes time and assumes you have the necessary tubes on hand. An easier technique is to use your VTVM. Set the instrument to read AC volts. Adjust the range selector so that you can read the line voltage somewhere around center scale. Turn the receiver on and check the reading across the filament terminals of each tube. Any tube that is in good working order will not produce a voltage indication on the meter. The tube that is defective, however, will read almost full line voltage. The technique for this test is diagrammed in Fig. 5-4.

Of course it is possible that the trouble may not be due to a tube, but caused by a defect in the power switch or in the connecting AC cord. In that case, connect your test lead to point A in the diagram, and then successively touch points B and C. If there is no voltage between points A and B, then the trouble is either in the line connecting to the power outlet, in the plug, or possibly in the outlet itself. If there is voltage between points A and B, measure between points A and C with the switch closed. If there is no voltage, the switch is defective.

Checking Coupling Capacitors

A coupling capacitor, such as the one shown in Fig. 5-5, has B-plus voltage on one side and returns to ground through a resistor on the other. While the function of the capacitor is to transfer the signal from one stage to the next, it must work under the constant strain of a DC potential. To this stress, add temperature, dust and dirt, plus the fact that capacitors usually work near the limit of their voltage rating, and you have a likely trouble spot in radio and television receivers.

To check the capacitor set your VTVM to read DC volts.

Set the range selector so that you can, if necessary, read the full B-plus voltage of the receiver. Connect the ground lead of the instrument to the chassis or B-minus line of the receiver. Using the DC test probe, check the plate side of the capacitor and then the side connected to the control grid of the following tube. Remove the tube from its socket. The DC voltage at the grid end should read zero. Rotate the range switch to some lower setting. At no setting of this control should you read any voltage. If you do, the capacitor is either leaky or shorted. If you read voltage with the tube back in its socket (other than the normal bias voltage) then the tube may be gassy (drawing grid current).

Checking the Local Oscillator

All superheterodyne receivers (whether AM, FM, or TV)

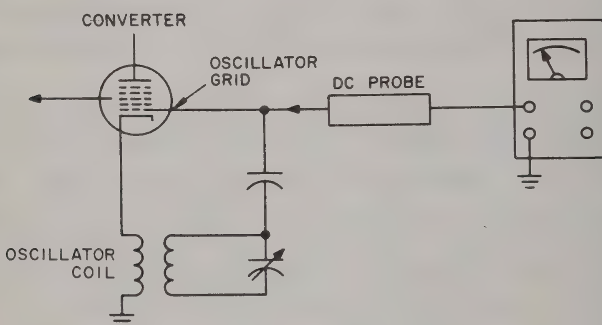


Fig. 5-6. A VTVM may be used to measure the grid voltage on an oscillator to determine whether or not oscillation is present.

make use of an oscillator to supply a reference signal which beats against the incoming signal to produce an intermediate frequency. Failure of the local oscillator means complete loss of sound in AM and FM receivers, and loss of sound and picture in TV sets.

To check local oscillator operation, use the arrangement shown in Fig. 5-6. Set your VTVM to read negative DC volts and touch the tip of your DC probe to the oscillator grid. The ground lead of the instrument should be connected to chassis ground or B minus. Depending on the type of receiver, the DC voltage developed at this point will be from 5 to 20 volts, or higher, so set your range selector accordingly.

You can use this test on other types of oscillators as well. If the oscillator is not functioning, tube bias will be very low, possibly even positive with respect to ground, and consequently plate current through the tube will be much higher than normal. If the tube is working into a resistive load, a large voltage drop will be produced across it, and as a result the voltage at the plate of the tube will be quite low. Thus, a DC voltage check at the plate of an oscillator tube, when you know what the correct operating voltage should be, is helpful.

It is sometimes possible for a receiver to pick up just a few stations, but fail to receive others or receive them only faintly. Here again, the problem may be due to the fact that the local oscillator does not work equally well over its entire tuned range. You can check, by connecting the VTVM as suggested, while rotating the tuning dial of the receiver. There should be some variation in the negative DC voltage indication, but it should not drop to zero or to some very low value. Trouble here may be caused by the plates of the variable tuning capacitor shorting at some particular setting of the tuning dial.

Checking Audio Amplifiers

There are three types of tests you can make on audio amplifiers with a VTVM. These include DC voltage measurements, signal voltage measurements, and resistance checks. To make resistance checks, make sure the audio amplifier is disconnected from any power source. Set the VTVM to read resistance and check, in turn, the primary and secondary winding resistances of interstage and output transformers. Remember, there is a world of difference between resistance and impedance. If you are following a circuit and you see that the winding of a transformer is marked as several thousand ohms, consider that this may mean impedance and not resistance. This is particularly true in the case of speaker voice coils, which normally have a DC resistance of only an ohm or less, but the impedance may be anywhere from 3 to 16 ohms. Reading zero resistance when making a voice coil check simply indicates that you have made a continuity test.

You can get some idea of the frequency response of your audio amplifier by connecting an audio generator to the input and a VTVM, set to read low AC volts, across the voice coil of the speaker. Set the gain control of the generator and the gain control of the audio amplifier so that an audible tone is

emitted from the speaker. Start your audio generator at some low frequency, and make a note of the audio voltage indicated on the meter. Repeat the test in steps of 1,000 cycles. Plotting a graph will give you an idea of the frequency response.

It is often desirable to measure the power output of a receiver or audio amplifier. One procedure for making power measurements involves the use of an output meter, which is usually calibrated in decibels. The AC voltmeter function of a VTVM and a resistive load can be used in place of an output meter. The resistive load must have the same value as the impedance of the receiver output and must have a wattage rating at least as great as the power expected from the equipment under test.

Since the meter can indicate only the AC voltage across the resistive load, the technician must do some simple computations to find the power. Fig. 5-7 shows a typical setup for checking the sensitivity of a receiver with an AC voltmeter

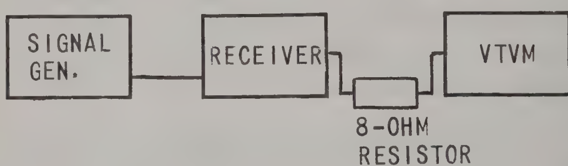


Fig. 5-7. Setup used to check audio output.

used as an output meter. This test requires that the audio frequency (AF) output power be at least of a certain value when a standard modulated RF signal is applied to the antenna terminals. If the load resistance is 8 ohms and the minimum power output required is 100 milliwatts, the voltmeter must indicate .89 volt AC or more. This value can be found by using formula $E = PR$. Another formula that can be used is $P = E^2/R$. Some VTVMs have a db scale, which makes it convenient to measure power and output levels in db. If your VTVM has this feature, the operator's manual will explain its use.

Taking Care of Your VTVM

We have mentioned a few precautions in the care of your instrument, notably in the proper use of the range and the function selector switches. Here are some other suggestions,

some of which may appear to be ordinary common sense, but sense is neither ordinary nor is it common.

1. From time to time, open your VTVM and examine the battery. Make sure it isn't corroded and that it sits firmly in its holder. If the holder is held in place with a screw make sure it is tight. Always use the correct battery replacement. Inability to zero-set means you should replace the battery.

2. Calibrate the meter from time to time using the method described earlier in this book. Replace the tube or the transistor in the VTVM if you have evidence that gain has decreased.

3. Always keep the meter function selector set to read volts. This will prevent undue wear of the meter battery because of shorting test leads.

4. If the test leads become intermittent, replace them. Don't roll up the test leads, but suspend them from a hook near your bench. It's helpful to use a red-colored lead for B-plus and a black lead for ground or common.

5. Clean the face of your meter with soap and water only. This does not mean soaking the meter. Just use a damp cloth. Do not use solvents of any kind. They can scratch and cloud the plastic face of the meter.

6. Your meter may come equipped with a setscrew for mechanical adjustment of the meter pointer. Use this adjustment only if the meter pointer does not rest on zero when not connected to the power line.

7. Manufacturers issue a manual with each VTVM they sell. This manual usually contains the circuit diagram of the instrument plus a general description of its use. Read this manual and become familiar with the circuit. It's your instrument and the more you know about it, the more you will get out of it.

CHAPTER 6

Servicing With the VTVM

When it comes to making voltage and resistance measurements, there is no sharp dividing line between the VOM and the VTVM. Many of the measurements described in this Chapter can be made with either instrument. But a test instrument is no substitute for common sense. For example, resistance checks can be made with either instrument. However, if using a VOM means trying to read the crowded end of a resistance scale, you shouldn't need to be reminded that perhaps your VTVM might have a wider range.

Technicians sometimes forget the relationship of the power supply to the circuits it serves. Every stage is a shunt load across the power supply, as shown in Fig. 6-1. Only a few representative tubes are shown to illustrate this point. It makes no difference if the set has two tubes or twenty. The arrows indicate the direction of current flow, which will aid in determining polarity and test lead connections. Table 6-I provides a series of VTVM checks for this representative circuit. These same tests can be performed on any type of similarly powered equipment.

Wafer Switch Troubles

You can resistance check wafer switches, but often this is not as easy as it sounds. If the wafer switch is a multi-deck type, you have to be in a position to examine the switch visually to see what happens as you turn the rotor. Unsoldering wires and components can be time-consuming and aggravating if subsequent checking shows the switch to be OK. Also, these switches usually have silver-plated contacts and wipers. If hot solder is accidentally dropped on them, it is practically impossible to remove it. Thus, it is advisable to make all the tests you can before disconnecting a wafer switch. Even

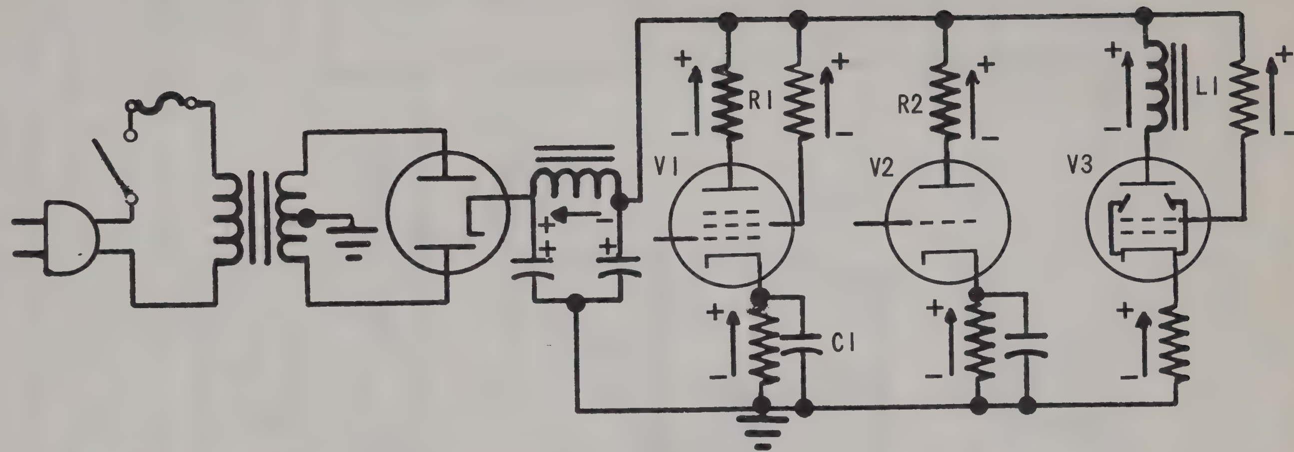


Fig. 6-1. Every stage is a shunt across the power supply.

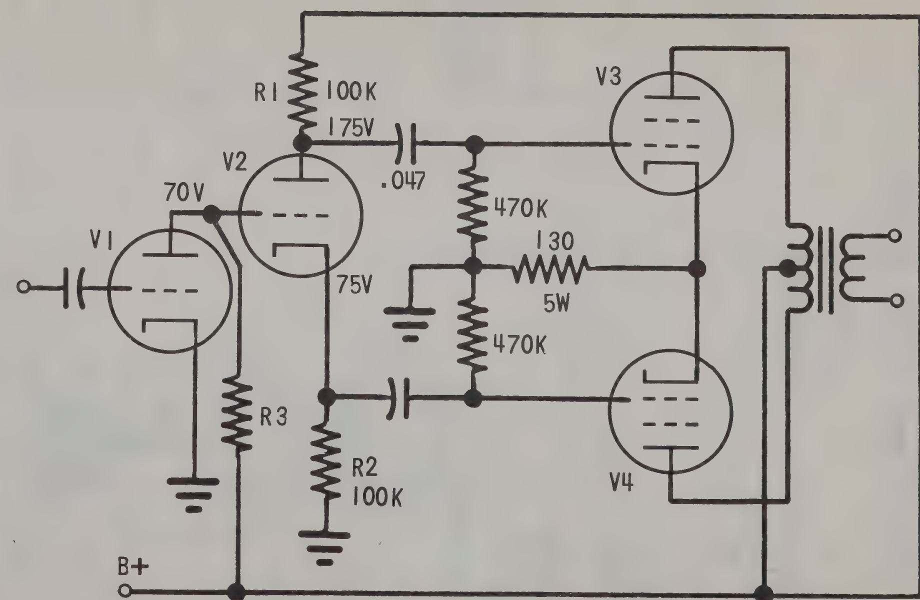


Fig. 6-2. In circuits of this type, control grid voltages can be fairly high with respect to ground.

then, your tests should let you put the finger of suspicion directly on a particular contact. Incidentally, if a wafer switch is jammed, brute force will only prove that you are stronger than the switch. The only cure for a jammed switch is a replacement. If you must replace a wafer switch, tag all leads so you will know where each connects.

A wafer switch is like any other kind. It should have positive action—that is, each contact should be either open or closed. If a resistance check with your VTVM shows a high value of resistance between a pair of open contacts, dirt and grime may be causing high resistance leakage.

The Hot Grid

Some service technicians like to perform "squawk" tests. This means putting your finger on the control grid of a tube and then listening for a resulting noise out of the speaker. Other technicians, a little more leery about sticking their fingers into a receiver that has high B-plus, prefer a "spark" test, shorting the grid to chassis with a screwdriver blade. There are times, though, when such tests are improper. Consider Fig. 6-2, for example. The plate of V1 is connected directly to the control grid of V2, and the potential at this point is 70 volts. This potential might not give you much of a shock, if at all, but why take chances? Grounding the grid momentarily will not cause any disaster, but it does subject R3 to the full B-plus voltage.

The circuit shown in Fig. 6-2 includes a phase inverter, driver and push-pull audio amplifier. Some of the troubles you might locate with a VTVM are outlined in Table 6-II. Before we leave Fig. 6-2, consider plate voltage measurements for a moment. If a tube normally has 150 volts on its plate with 3 volts of cathode bias, measuring between plate and ground produces an error that is so small it cannot be read on the meter. Consider V2, though. Its plate is marked 175v. This doesn't mean that it has 175 volts on its plate. The plate voltage is 175 volts minus the cathode voltage (75 volts), only 100 volts. The bias is the potential difference between the control grid and cathode, just 5 volts. Proper operation depends on equal value resistors for balance. Resistance check the plate and cathode resistors of V2 and the grid return resistors of V3 and V4. Distortion results if these resistors

Table 6-1. VTVM Checks For Typical Line-Powered Device.

TROUBLE SYMPTOM	VTVM CHECK
No AC input voltage.	Set the VTVM function switch to ohms and connect the test leads across prongs of male plug. Operate on-off switch of receiver. Meter pointer should swing back and forth. If not, place test leads across fuse. Meter should read zero ohms. If fuse is OK, place test leads across switch. Turning switch on and off should cause meter pointer to swing back and forth between zero ohms and infinite resistance. If switch is OK, resistance check primary winding on power transformer. This will vary, but on average will be less than 5 ohms. If reading is OK, check outlet. Set VTVM to AC volts and insert test leads into outlet. Trouble is sometimes due to defective female connector in outlet or to prongs of male plug not making contact in outlet.
No B-plus voltage.	Look at rectifier tube. If there is no filament glow replace the tube. If new rectifier doesn't restore B-plus voltage, check for AC voltage between each plate of rectifier and ground.
Excessive hum.	Electrolytics in filter section may have lost capacity. Shunt existing capacitors with equivalent units. Watch polarity. Make sure voltage rating is equal or greater. Drop in hum indicates insufficient or poor filtering. Replace electrolytic unit.

No. B-plus across output filter.	Set VTVM to read DC volts, with range switch set to read 300 volts or more full scale. Measure B-plus from cathode of rectifier to ground. Correct B-plus indicates that filter choke (or filter resistor if used) is open.
Excessive voltage on plate of V1.	If voltage on plate of V1 is equal to B-plus, tube is not drawing current. Try a new tube. Check plate load resistor R1 and cathode resistor by setting VTVM to measure resistance. (Make sure set is off.) Excessive bias on V1 can also cause this condition. The voltage on the plate of V1 can be higher than normal, but not as high as power supply voltage if there is some trouble in the screen circuit. Measure voltage drop across screen resistor. No voltage indicates no connection to screen, open screen dropping resistor, or defect in tube.
Insufficient voltage on plate of V1.	Cathode bias resistor may be too low in value or shunting bypass capacitor may be leaky. Set VTVM to resistance function and check the resistor. Connect VTVM to plate and cathode of tube and set for DC volts. Disconnect C1 and note if plate voltage increases. If it does, replace C1.
No sound output.	L1 represents the primary winding of the audio output transformer. You should have B-plus voltage on both sides of this winding.

Table 6-11. VTVM Checks For Audio Amplifier Troubles.

THE TROUBLE	VTVM CHECK
No output.	Set the VTVM to AC volts (about 10 volts full scale) and connect it across the secondary of the audio output transformer. Connect an audio coupling capacitor to the "hot" test lead of a signal generator and inject an audio signal to the control grids of V1, V2, V3, and V4, in succession. Make visual check to see if tube filaments are lit. Measure B-plus voltage (should be 200-250 volts DC). No output with signal applied at grid of V1 is positive indication amplifier section is inoperative. Output with signal applied at grid of V2 indicates V1 is defective. Output with signal applied at grids of V3 and V4 (should give equal output) is an indication of trouble in stage V-2—measure tube voltages.
Distorted output.	V3 and V4 must receive equal values of signal voltage. Distortion can be caused by unbalanced plate or grid voltages. Check plate voltage of V2, with VTVM function selector set to read high DC volts. Measure between plate and cathode, <u>not</u> between plate and ground. Measure DC bias between control grid and cathode. As a further check, keep VTVM set in DC voltage function, on high range. Connect one test lead to plate of V3; other lead to plate of V4. Voltage reading should be zero. Start with high range, DC volts, then gradually move range selector to lowest value. A voltage reading indicates imbalance. Could be caused by tubes that aren't matched.

Table 6-III. VTVM Checks of Ratio Detector Operation.

THE TROUBLE	VTVM CHECK
No sound.	Set VTVM to read low AC volts and connect it across the two outer terminals of volume control, R1. Inject a modulated IF signal at the plate of the last IF amplifier tube. If you get no sound output, the detector is in trouble. Difficulty, other than defective tube, is an open component.
	Set VTVM function selector to OHMS and resistance check the last IF transformer, the radio-frequency choke (RFC) and the volume control. Sound will be lost if C1 is open. Check by substitution Watch polarity.
Distortion	Usually caused by misaligned IF transformer.

aren't matched. It is more important for R1 and R2, for example, to be equal in value than to be exactly 100K.

FM and TV Detectors

You'll find three different types of detectors used in FM and TV sets—the ratio detector, the discriminator, and the gated-beam detector. Troubles with these detectors usually (but certainly not always) fall into two categories—weak tubes and/or an IF transformer begging for realignment. Fig. 6-3 shows a typical ratio-detector circuit. Table 6-III outlines VTVM checks.

Troubleshooting the gated-beam detector shown in Fig. 6-4 is similar, except that the tube itself is a common source of trouble. If the sound is weak or distorted, replace the gated-beam tube as a first choice. If there is no sound, check plate and bias voltages. Also resistance check IF transformer L1 or quadrature coil L2 for open windings.

You will still find the discriminator (Fig. 6-5) used in some FM receivers, although it has been largely replaced by the ratio detector. In theory, the ratio detector does not need

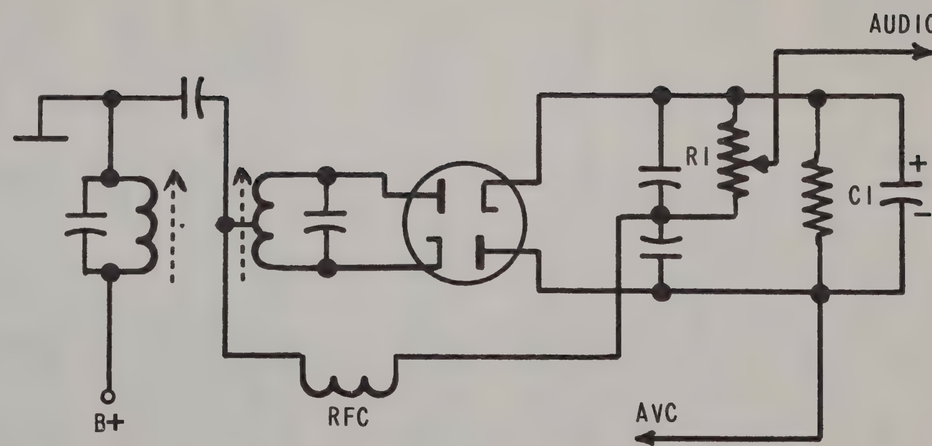


Fig. 6-3. Schematic of a typical ratio detector.

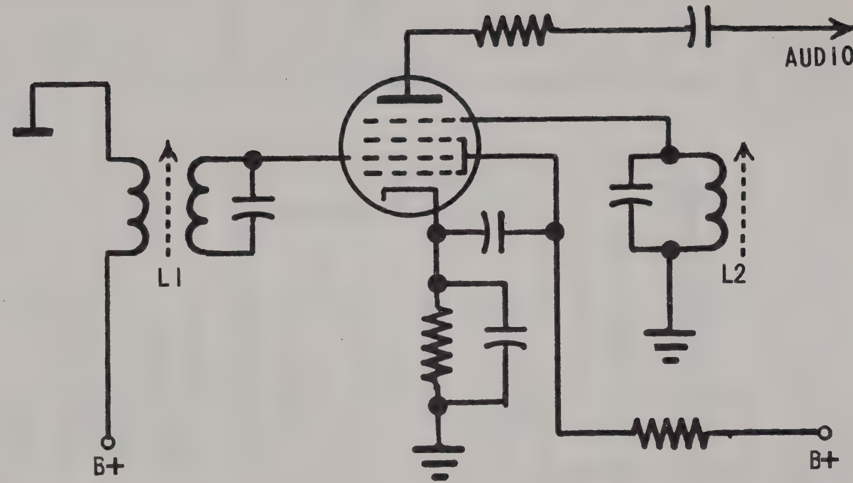


Fig. 6-4. Schematic of a typical gated-beam detector.

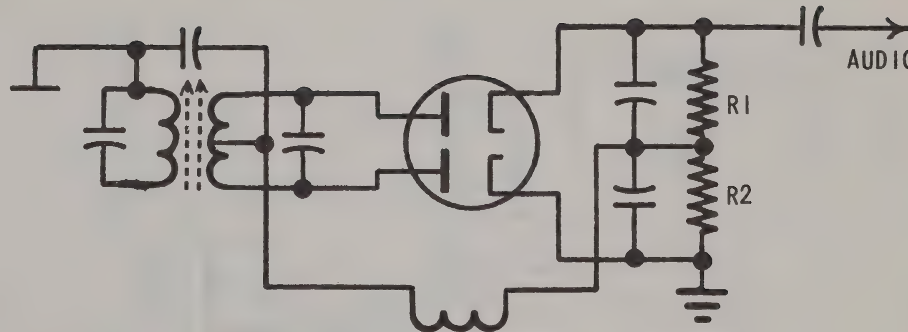


Fig. 6-5. This discriminator circuit was once quite popular.

limiter circuits ahead of it, although you will find some FM sets in the higher quality brands that use a ratio detector and one or more limiter stages. Use the same servicing techniques on the FM discriminator that you employ on the other detector types. R1 and R2 should be equal in value.

Troubleshooting the Limiter

Fig. 6-6 shows a limiter circuit. Its function is that of a clipper, designed to eliminate amplitude variations in the signal. To check its operation, set the VTVM on its DC voltage function with the range selector at 10 volts. The top end of R1 is negative, the bottom end positive. Tune in a signal and note the voltage drop across R1. No voltage across R1 can mean a defective limiter tube or failure of some previous stage to deliver the signal. DC voltages on the plate and screen of the tube should be low. A higher-than-normal voltage can permit noise to go through to the detector stage. Check the voltage on the screen grid by measuring between screen and ground.

Checking IF Stages

Whether the IF is for AM or FM, basic testing is the same. No sound usually means a defective tube. However, you can have weak sound even if tube emission is extremely weak. If the signal is strong enough, there is sometimes sufficient interelectrode capacitance in a tube to transfer a small part of the signal to the following stage. The fact that a tube filament lights is no indication that the tube works properly. A VTVM can be used to check the DC operation of an IF section. You can measure plate and screen voltages and AGC or AVC bias, and you can resistance check IF transformers and other components. Using the AC function, evidence of signal output can be obtained by measuring across the volume control (or the contrast control in a TV set).

AGC (automatic gain control) or AVC (automatic volume control) voltage controls the DC bias for IF and front-end tubes. To measure either AVC or AGC, set your VTVM function selector to read DC volts on the low range. The polarity is as shown in Fig. 6-7. Connect the test leads across C1 and tune in a strong station. The pointer should swing as you

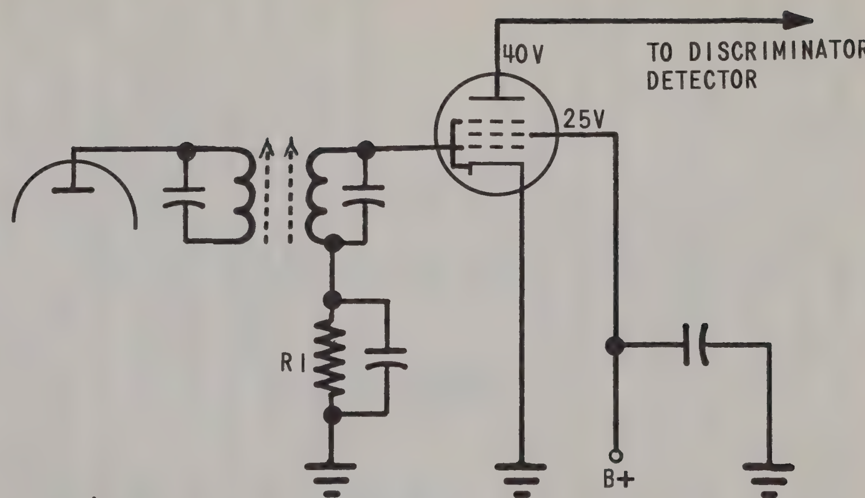


Fig. 6-6. Schematic of a simplified limiter stage.

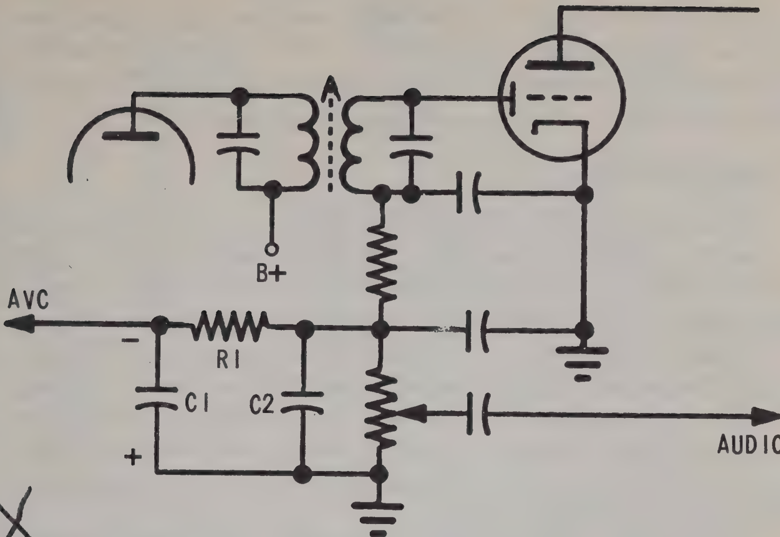


Fig. 6-7. AVC or AGC voltage polarity is negative with respect to ground in this circuit.

rotate the tuning dial from no station to strong signal. If this doesn't happen, place the test leads across C2. A DC voltage variation here means you should check out R1 and C1. You can also check AVC by setting your VTVM for low DC volts and measuring the voltage at the grid of one of the controlled tubes.

Checking FM Front Ends

The basic idea of the front end in an AM or FM receiver is the same. The signal is changed from an RF to an IF range. Complete loss of signal can be caused by local oscillator failure. Check the local oscillator bias voltage by setting your VTVM to its minus DC voltage function, with the range switch for about 30 volts full scale. The amount of bias voltage will depend on the setting of the tuning control and will also vary from receiver to receiver. Look for a bias up to about -15 volts.

Failure of the local oscillator doesn't always mean complete absence of signal. If the receiver picks up one station only and tunes rather broadly, the set may be acting as a TRF (tuned radio frequency) receiver. The local oscillator may be working, but not with the enthusiasm it should have due to

weak cathode emission. The result will be weak output, with an inability to pull in some stations. You can verify by checking the bias voltage. If it's down to around about 1 volt, try another tube.

Signal Substitution

The signal substitution method can be used in troubleshooting a weak or dead FM receiver. For troubleshooting by signal substitution, a sweep signal generator is preferable, because its signal can be heard in the output of the receiver. If such a signal generator is not available, the same type of instrument that is used for AM receivers may be employed, although it is not as convenient as the type that produces a sweep signal. The signal generator must produce frequencies that are equal to the tuning range of the receiver and to its intermediate frequency (or frequencies).

When testing a weak receiver, checking stage gain by listening to the output is not a dependable procedure. An increase in signal input level may not result in a corresponding increase in output level because of the limiting action of the limiter stage. Also, identical output levels for a signal injected in the plate circuit and for a weaker signal at the grid do not indicate that a stage is amplifying. The limiter may have reduced the signals to the same level. The best way to check the gain of the RF and IF stages is to measure the strength of the signal that is applied to the control grid of the limiter. This can be done in two ways:

(1) Use a VTVM with an RF probe and measure the RF voltage directly.

(2) If the limiter stage is the type that develops grid-leak bias, use a VTVM to measure the DC voltage between control grid and ground. The voltage will increase with an increase in signal strength.

A VTVM may be used to measure the gain of an RF or audio stage by injecting a suitable signal at the input (RF or audio as the case may be). Using an appropriate AC scale (start with a higher scale and work down), measure the input signal, then switch the probe to the stage output and measure again. By dividing the first reading by the second, you'll know the approximate gain that stage is contributing. Of course, the same procedure can be used to measure the cumulative gain of several stages in cascade.

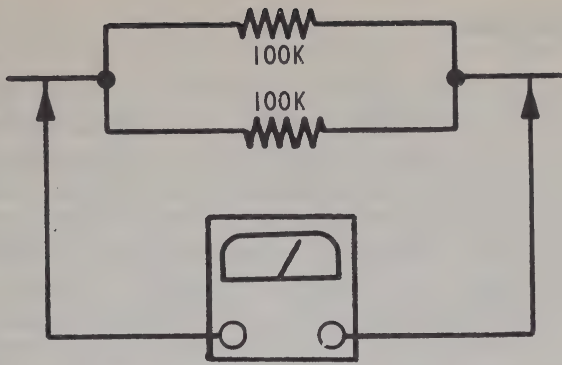


Fig. 6-8. If the resistance reading here is 50K, both resistors are OK.

Audio voltages should be almost equal in push-pull output stages; they shouldn't differ by more than 10% from both control grids to ground and from both plates to ground. The same is true with a preceding push-pull driver stage. To check, inject a test signal at a point ahead of the push-pull stage (s), and measure the grid voltages. Usually, it is sufficient to measure only grid signal voltages. Should it be necessary to measure plate signal voltages, remember the high DC voltages normally present on tube plates.

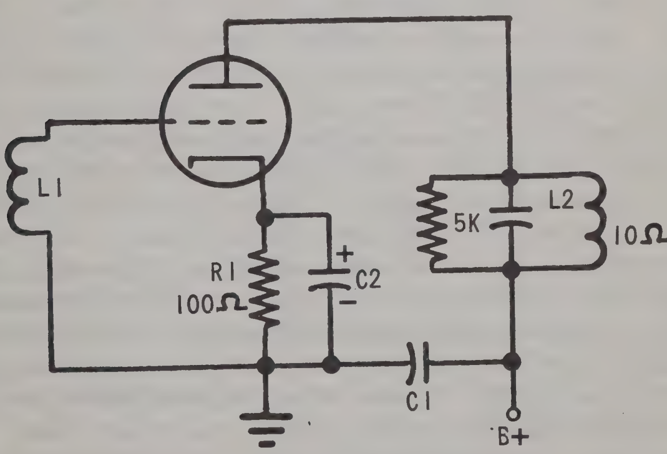


Fig. 6-9. You should be able to pinpoint defective components in this circuit before unsoldering any connections.

Quite often you will want to resistance check some component in a receiver but dislike the idea of unsoldering one lead. Quite right. It's work and there's no reason for working if it isn't necessary. Some technicians, of course, always unsolder one lead of the component being checked, just as a matter of routine, but this is simply because they would rather work than think. As a simple example, consider the two parallel resistors shown in Fig. 6-8. Each resistor is 100K ohms. You would like to check both resistors. Since the shunt equivalent is 50K ohms, a reading of approximately this amount on either your VOM or VTVM will tell you that both resistors are OK. If one of the two resistors had opened, your meter would indicate 100K ohms. And if one of the two had shorted, you would read zero ohms. But suppose one of the resistors had changed value? If, for example, your meter told you that the equivalent resistance was 60K ohms, you would have good reason to suspect that one of the two resistors had increased in value. Then, and only then, would you have some justification for reaching for your soldering iron.

That was a simple example, so let's consider one that isn't so obvious. Suppose you want to check the components of a triode circuit like the one in Fig. 6-9. With the receiver turned off you can check the resistance of L1. On the other hand, with the receiver turned on, you can measure the bias voltage between grid and cathode. Which test is better? The voltage test! With the resistance test you checked a single component, L1. The voltage test indicates that both L1 and cathode resistor R1 are okay. If you get no bias voltage, you still do not need to reach for your soldering iron, at least until you make other tests, including substitution of the tube.

Now suppose you were suspicious of the components in the plate circuit. You can make a quick overall test by measuring the DC voltage between plate and cathode. A correct voltage indicates that there is no need for unsoldering any of the plate circuit components. If plate voltage is much lower than normal, you should be suspicious of the 10-ohm plate coil. Is it time for the soldering iron yet? No, you're suspicious, but not sure. Consider the three plate components—a resistor, a coil, and a capacitor. The DC resistance of the combination

should be close to 10 ohms. If the 10-ohm coil opens, the resistance will be 5K ohms. The voltage drop across the resistor will increase, and the plate voltage on the tube will decrease. A quick resistance check will tell you whether or not the coil is open.

In-circuit testing is not difficult if you know what to watch for. Look for shunt components. Be careful, though. Two parts may be in parallel, but not necessarily adjacent to each other in the circuit diagram. Further, it isn't always easy to recognize shunt components. You need to have a knowledge of circuits and how they work. To illustrate this further, consider the circuit shown in Fig. 6-10. This is an ordinary crystal diode detector of the type used in radio and TV receivers. But therein lies a difference. Suppose the detector is in a TV set, with the load (R) somewhere between 2K and 4K. Can you resistance test the crystal in-circuit?

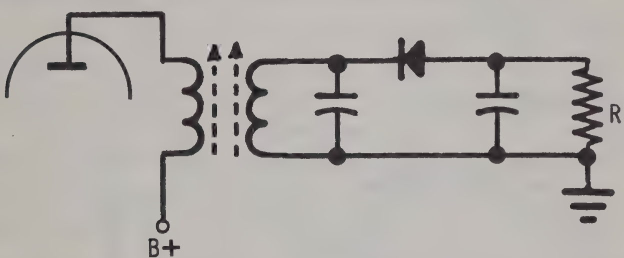


Fig. 6-10. Resistance checking this crystal diode circuit requires that the parallel resistance of the load be taken into consideration.

Let's assume the forward resistance of the crystal is about 200 ohms and the reverse resistance around 100K. If the load is, say, 3,000 ohms, a forward resistance check of the crystal measures 200 ohms in parallel with 3,000—so the net should be fairly close to 200 ohms. But what about the reverse resistance check? We will have the reverse resistance of 100,000 ohms in parallel with 3,000, so the net measurement will be close to 3,000 ohms. The test isn't valid since we do not know if the resistance ratio of the crystal is good or not.

Now suppose the circuit is for an AM receiver. Load resistor R could be a 250K volume control. Quite a difference. You would still measure about 200 ohms when checking the forward resistance of the crystal. But for the reverse resistance check, the 250K ohms of the load will be in parallel with 250K, or a net measurement of a little over 71K. While

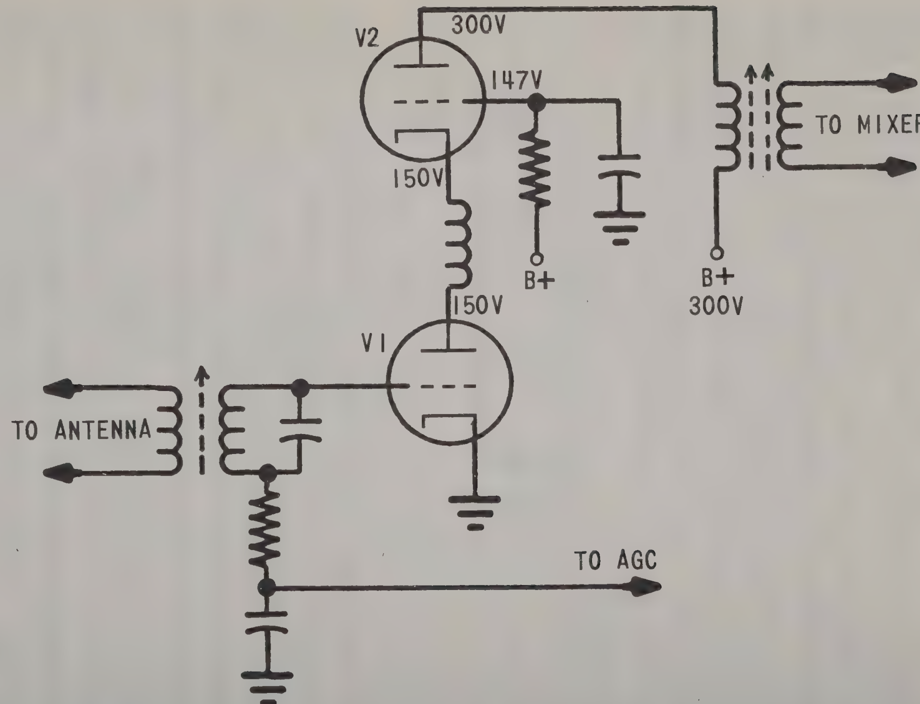


Fig. 6-11. The control grid of V2 is hot with respect to ground in this cascode circuit.

the test will not give you a true resistance ratio of the crystal, it will tell you if the crystal is defective or not—and that's the basic purpose of the test.

Somewhat earlier we described a direct-coupled circuit with the intention of showing you that from a voltage viewpoint, a control grid can be "hot" with respect to ground. Another such circuit, a cascode RF amplifier, is shown in Fig. 6-11. You will find this circuit most commonly used in FM and TV receivers. The tube is usually a double triode. As you can see, the cathode of V2 is "hot." It's 150 volts above ground and the control grid is just a few volts less. What is the plate voltage of V2? The circuit shows 300v, but that is the voltage with respect to ground. The difference between plate and cathode is only 150 volts. Always think of plate voltage as the amount of drop across the tube and you will become accustomed to thinking of the cathode rather than the chassis.

You can check the circuit of Fig. 6-11 quite nicely with either a VOM or VTVM. Set the function to DC volts and the range to at least 300 volts full scale. V2 is a grounded-grid amplifier. Yes, we know—there is a big resistor hanging on to the grid, but its only purpose is to supply the grid with B-plus. The grid is grounded, as far as RF is concerned, through the bypass capacitor tied to it. The circuit is used as an RF amplifier, so a weak tube means weak or distorted sound in an FM receiver, and a snowy picture for a TV set.

Another case of tubes connected in cascode is shown in Fig. 6-12. Here the sync separator stage (and often several others as well) is in series with the audio power amplifier. The power amplifier, capable of carrying heavy current, serves as a voltage divider across the 250-volt B-plus line. Thus, the DC current of the sync separator (and of any other tubes connected to the 150-volt supply line) flows through the audio output stage.

Why are such circuits used? Generally, all tubes in a radio or TV set are in parallel, each one adding to the load on the power supply. Operating tubes in series permits "sharing" of B-plus current. If the audio output tube, as an example, requires 40 ma, this same current can be used to operate a number of other tubes. The sync separator used in the example circuit works with much less current than 40 ma. Thus, you will find other tubes connected in parallel with it—IF tubes, video amplifier tubes, etc.

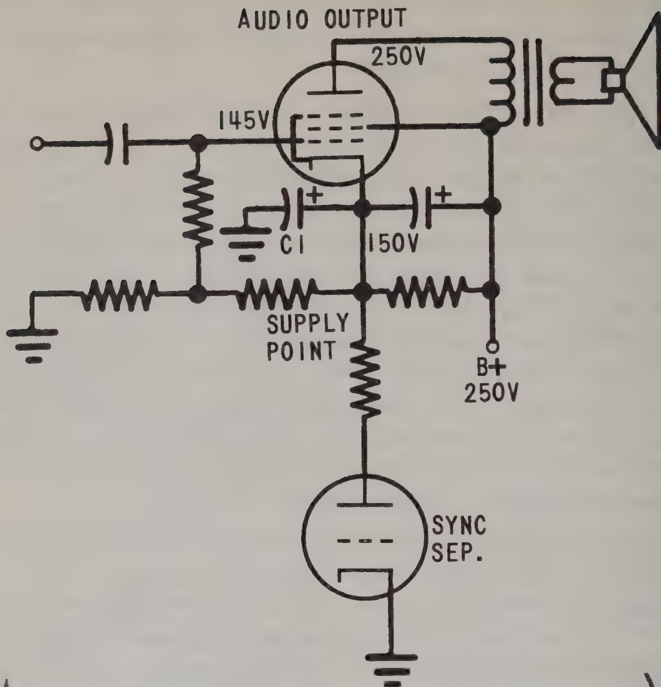


Fig. 6-12. In this cascode circuit the audio output stage is used as a B-plus voltage divider.

Does this present servicing problems? It certainly does. For example, one of those parallel tubes may become weak or completely inoperative, upsetting the current distribution. B-plus current through the audio tubes decreases and its output is weakened. Conversely, if the audio output tube becomes weak, current supplied to the tubes in parallel is diminished. What happens depends on the stages involved and how critical they are. Usually, the sync circuits are affected first, then the IFs. Complete failure of the power amplifier results in no sound and no picture. Another way of checking series tubes is with a scope, so we'll come back to this type of circuit in a later Chapter.

PART III

THE OSCILLOSCOPE

How It Works

How To Use It

Servicing With the Scope

CHAPTER 7

Understanding the Oscilloscope

The oscilloscope, more familiarly knows as a scope, is basically a simple piece of equipment. Yet, more than any other test instrument, the scope calls for a greater degree of understanding and technical skill. It rewards that understanding with a tremendous amount of information, often not otherwise obtainable. Scale type meters are easy to read compared to the scope. The scope is one of the few instruments that requires interpretation of the information it presents. Further, misadjustment of the controls may make its information inaccurate or difficult to understand. Why bother with a scope? Because it presents its information in a way that no other instrument can imitate. With the help of the scope you can determine exactly what voltages and currents are present in a circuit. You can see at once the effects of changes in electronic components. The proper setting of the controls is important—in fact, essential—for unless you know exactly what each control is supposed to do, the waveform pattern you see on the screen will be meaningless. However, to know just what each control is supposed to do, you must know the job of each scope circuit.

The Cathode Ray Tube

The heart of the oscilloscope is the cathode-ray tube, abbreviated CRT. The only purpose of the circuits connected to this tube are to make it display the information you seek. The CRT is a first cousin to the picture tube in a television receiver, but that is just about where the relationship ends. As in the case of many vacuum tubes, the CRT contains a heated cathode as its source of electrons. In an ordinary vacuum tube, electrons generally travel to the plate like radii from the center of a circle. In the CRT, though, a stream

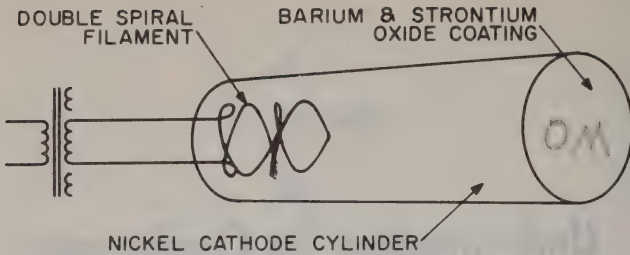


Fig. 7-1. The CRT filament is connected to a separate winding on the power transformer, as shown here. The only purpose of the filament is to heat the cathode.

of electrons flows in a straight line. For this reason the cathode is constructed like a cylinder, as shown in Fig. 7-1. The circular surface or face of the cylinder is coated with oxides which release large quantities of electrons when heated. These electrons form sort of a cloud having no particular shape or boundary. So the first objective is to control the movement of these electrons and then to "focus" them into a narrow, well-defined beam.

These objectives are achieved with a control grid, as shown in Fig. 7-2, a cylinder large enough to surround the cathode. The control grid looks like a miniature tin can, open at one end and with a hole in the center of the other end. In normal operation the control grid is negative with respect to the cathode, and its repelling force tends to form the electrons into the shape of a beam. At the same time, control of the potential between control grid and cathode provides a means for limiting electron flow to the plate, or face, of the tube. This potential, or bias, is adjusted by means of a brightness control or intensity control (see Fig. 7-3). The bias voltage range is between a few volts and more than a hundred volts.

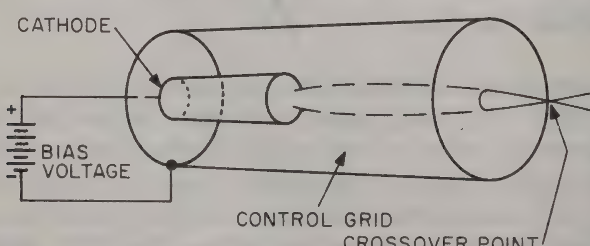


Fig. 7-2. The CRT control grid is a cylinder enclosing the cathode. A tiny hole in the front of the grid structure allows electrons to pass through.

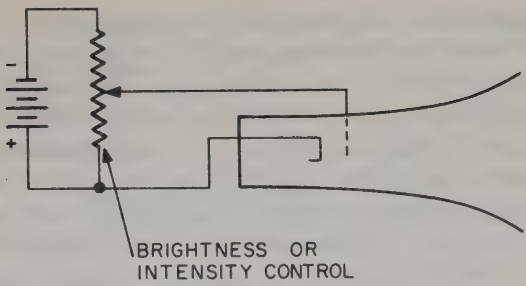


Fig. 7-3. The setting of the brightness or intensity control determines CRT bias and the brightness of the trace on the scope screen.

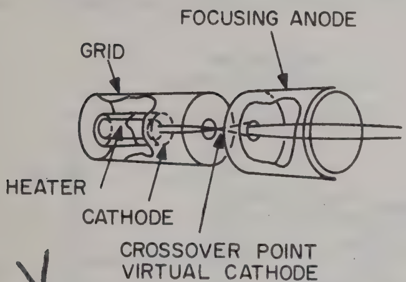


Fig. 7-4. The first or focusing anode is used to help shape the electron beam. Because the voltage on this anode is positive with respect to the cathode, it also helps accelerate electrons toward the CRT screen.

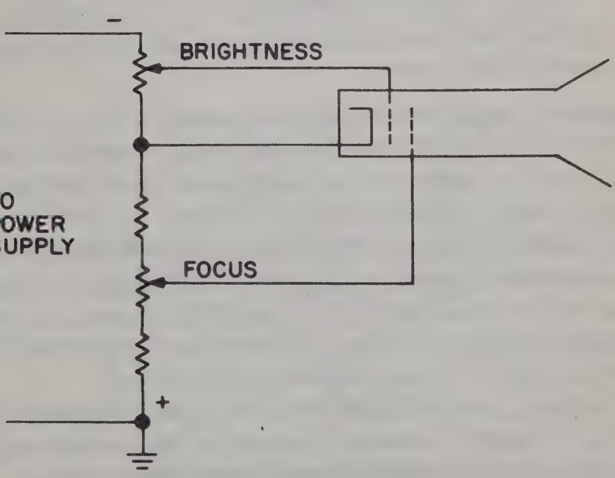


Fig. 7-5. The brightness and focus controls are part of the power supply bleeder network.

The control grid also supplies focusing action. Thus, the electrons come to a focusing point or a crossover point shortly after passing through the control grid. This crossover point is sometimes called the "virtual cathode." Due to the control grid cylinder's effect on the shape of the electron beam, intensity control adjustment may have some effect on focusing.

After the electrons leave the control grid, they pass through a focusing anode. As shown in Fig. 7-4, this element, also known as the first anode, is another cylinder with small openings on each end to permit the entry and exit of electrons, and it is generally several hundred volts positive with respect to the cathode. As shown in Fig. 7-5, the focus control, a potentiometer located on the front of the scope, varies the voltage applied to this element.

The accelerating anode, or second anode, serves to ac-

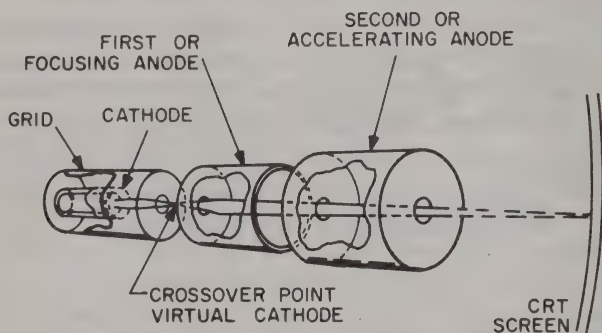


Fig. 7-6. The second anode accelerates the electron beam toward the CRT screen.

celerate the beam toward the flourescent screen at the front of the CRT. Fig. 7-6 shows that this anode resembles the first anode, but it is larger and is positioned closer to the screen. Electron beam acceleration is attained by putting a much higher positive voltage on this element than on the first anode. The accelerating anode is connected internally to a conductive coating on the inside surface of the CRT. Known as aquadag, the coating extends all the way from the second anode to the front of the CRT, almost reaching the screen.

The cathode, control grid, and the first and second anodes comprise a unified assembly known as the electron gun. Its sole function is to produce an electron beam and the means for controlling its intensity and focal point. Between the cathode and the screen, the electron beam goes through two cross-

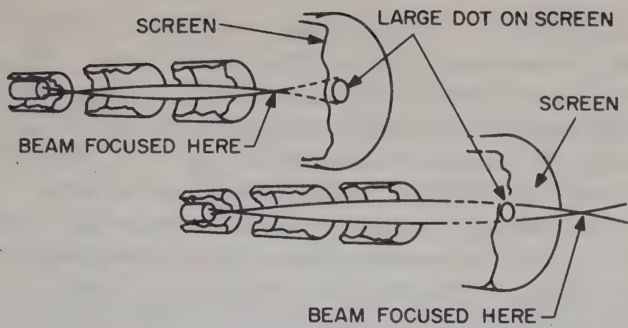


Fig. 7-7. The focus control must be adjusted so that the second crossover takes place at the screen of the CRT.

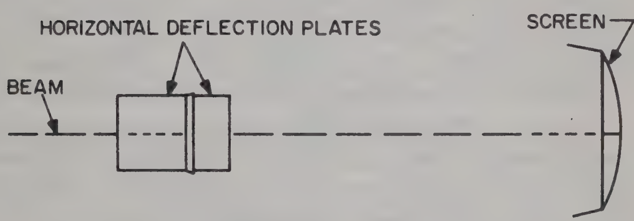


Fig. 7-8. The horizontal deflection plates are positioned in the vertical plane. The electron beam passes between them on its way to the screen.

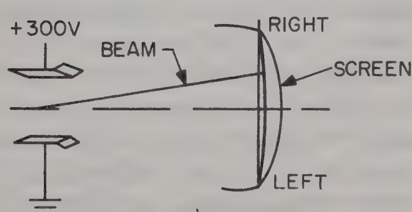


Fig. 7-9. A positive potential on one of the deflection plates bends the beam from its center position toward the right (as you face the screen).

over or focal points. One of these is at the point of the virtual cathode, immediately following the control grid. The second crossover may occur before the screen, at the screen, or beyond the screen. Correct focus is achieved only if the crossover is at the screen, as shown in Fig. 7-7. Proper focus is achieved by adjusting the intensity for suitably visible screen brightness, then setting the focus control for minimum dot size. It may be necessary to work back and forth between the two. Excessive brightness may result in a halation, a sort of glow which surrounds the dot of light on the screen.

The inside of the CRT's glass face plate is coated with a special phosphor which glows when bombarded with electrons. The glow does not disappear when the electrons move away from their point of impact, but instead continues for a brief period of time. The length of time the glow continues, called persistence, is a property of the phosphor chemicals and may be rated from very short to very long. The color of the glow on the average oscilloscope CRT is green, but CRTs can be made to produce white, blue, orange, red, or yellow. Most often the color of fluoresence and phosphorescence is the same. That is, a tube that fluoresces in a green color also will phosphoresce in that same color. However, if is possible to produce CRTs that fluoresce in one color and phosphoresce in another. Thus, the color of fluoresence may be blue-white and that of phosphorescence may be yellow.

Beam Deflection

Fig. 7-8 shows how we can use a pair of metal plates, known as deflection plates, to control the horizontal motion of the electron beam. This pair of plates, located a short distance beyond the second anode, are in a vertical position. With no voltage on the plates, the electron beam will be unaffected. But suppose we make one plate positive with respect to the other? As shown in Fig. 7-9 the positive potential will attract the electron beam, "bending" it away from its central position and causing it to strike the screen off center. If you had been watching the screen during this "bending" action, you would have seen a trace of light, somewhat like a line, and then the dot of light in its new position. We can move the dot of light in the other direction simply by reversing the potential applied to the deflection plates.

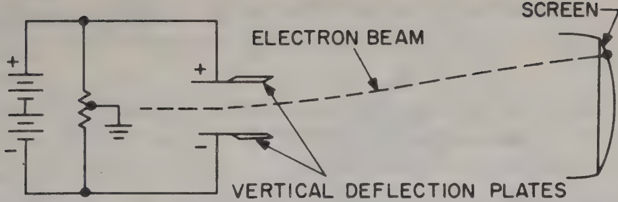


Fig. 7-10. Using push-pull deflection, one plate attracts the beam while the other repels it.

In actual practice, beam deflection is somewhat more complex. Because of its high velocity, a strong electrostatic force is needed to deflect the electron beam. Better results are achieved by using a push-pull arrangement. Fig. 7-10 shows the basic idea; one plate is made negative, the other positive. The negative plate repels the electron beam; the positive plate attracts it. Actually, as far as the DC voltage on the deflection plates is concerned, all that is needed is a potential difference between the plates. Thus, we could have a positive potential on both plates. The beam would be deflected if one of the plates was made more positive than the other.

To get vertical deflection of the cathode-ray beam, another pair of deflection plates is used. These plates, as shown in Fig. 7-11, are placed between the horizontal deflection plates and the screen. Physically, this set of plates is in the horizontal plane, and the effect is to move the electron beam up or down. Vertical deflection is obtained in exactly the same manner and using the same techniques employed for horizontal deflection.

Using both pairs of plates the beam (Fig. 7-12), and the dot of light it produces on the screen, can be positioned as desired. In an actual scope, the voltages on the vertical and horizontal deflection plates are controlled by a pair of poten-

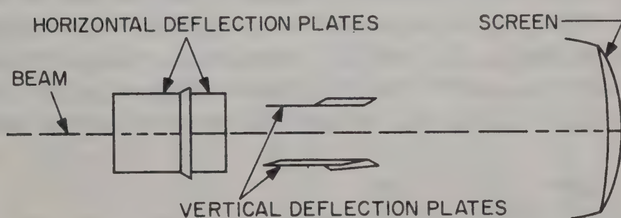


Fig. 7-11. Vertical deflection is achieved with a second pair of plates, positioned in the horizontal plane.

Vertikol

Y POZIT

X HORIZONTAL POZIT X

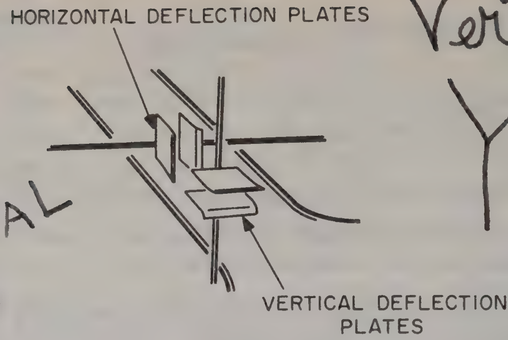


Fig. 7-12. Drawing showing the configuration of the vertical and horizontal plates.

tiometers. The vertical centering control is also known as the Y position adjustment. The horizontal adjustment may be marked horizontal centering or X control.

All controls discussed thus far relate to control of the electron beam: intensity, focus, and X and Y position controls. On some scopes you will find a separate on-off switch, while on others the switch is part of the intensity control. Some scopes come equipped with a beam control switch, used to turn the electron beam off when a pattern on the screen is not being observed. The same effect can be achieved by turning down the intensity control. The idea is to protect the screen against ion burns when a stationary pattern must be observed intermittently for a long period of time.

Horizontal Sweep

To provide a base line for waveform reproduction, we need a voltage on the horizontal deflection plates that will deflect the electron beam from left to right at a uniform rate of speed, and return to the starting point as quickly as possible. The type of voltage that meets these requirements, as shown in Fig. 7-13, is a sawtooth wave. Applied to the horizontal deflection plates, the steadily increasing voltage from time a to b will cause the beam to move uniformly from left to right. Then, during time b to c, the rapid change in polarity

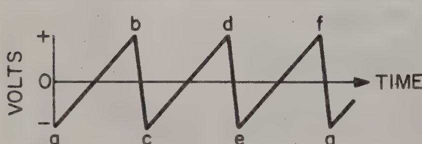


Fig. 7-13. Sawtooth wave for horizontal sweep.

will quickly deflect the beam back to its starting position. Changing the amplitude of the sawtooth changes the length of the sweep.

It takes the beam a definite amount of time to move from the left side of the screen to the right, providing a means for measuring time. Thus, if it takes the beam one second to travel across the screen, it will cover half the distance in one-half second and one-tenth the distance in one-tenth of a second—assuming, of course, that the sweep is linear. Consequently, we can regard the horizontal sweep as a time scale, and for this reason it is often called a time base. By varying the frequency of the sawtooth deflection wave, any desirable time base can be produced.

Vertical Deflection

Let us now assume that we have applied a sawtooth voltage of sufficient strength or amplitude to our horizontal deflection plates to produce a suitable time base line on the screen. If we apply a sine-wave voltage to the vertical deflection plates, it will be reproduced on the CRT screen as shown in Fig. 7-14. While the sawtooth voltage deflects the beam horizontally, the sine wave moves it up and down. Thus, to produce a waveform on the screen, both vertical and horizontal beam deflection is required. Horizontal sweep voltage is usually supplied by circuitry inside the scope. The voltage to be examined is brought into the scope via the test leads connected to the front panel.

The voltages applied to the deflection plates are AC voltages, and as such they have a certain frequency. Now let us suppose the sawtooth sweep voltage has a frequency of 100 Hz (cycles per second), and that the sine wave input to the vertical deflection plates has the same frequency. While the sine wave goes through its first half cycle, the sawtooth will move the beam halfway across the screen (assuming that the sawtooth and the sine wave forms both start at exactly the same moment). The result will be as shown in Fig. 7-15, one complete sine-wave cycle displayed on the CRT screen. Now suppose we change this 1:1 frequency relationship by reducing the frequency of the sawtooth to 50 Hz (cycles per second). The sine wave will complete two cycles while the sawtooth completes only one; thus, we will see two complete sine waves on the screen (Fig. 7-16). On the other hand, if we increase the frequency of the sawtooth to some odd value, such as 120 cycles per

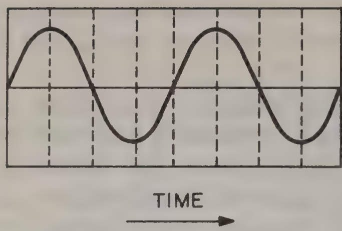


Fig. 7-14. With a sawtooth voltage applied to the horizontal deflection plates and a sine wave input to the vertical deflection plates, the pattern shown on the screen will be a sine wave.

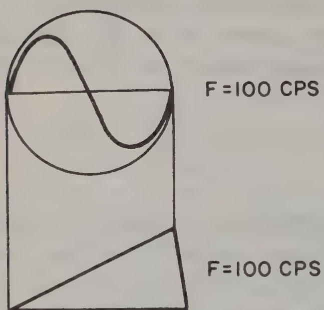


Fig. 7-15. When the frequency of the sawtooth sweep and the sine wave input are the same, a single cycle will be displayed on the screen.

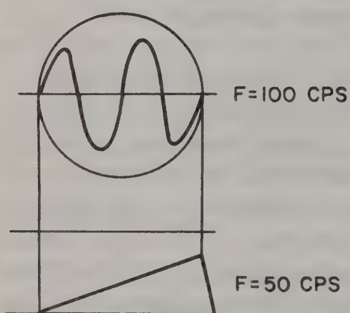


Fig. 7-16. If the sawtooth frequency is decreased, we will see more cycles of the waveform on the screen. Shown is a 2:1 ratio.

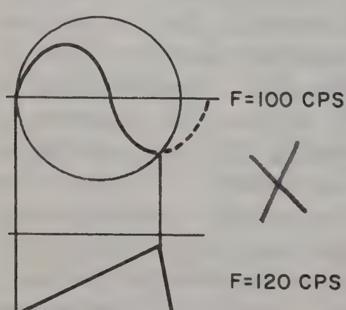


Fig. 7-17. Here the input frequency is 100 cps, but the horizontal sweep has been increased to 120 cps. The result is that only part of the input waveform appears on the screen.

second, we would see only a part of the sine wave, as shown in Fig. 7-17.

The internal sawtooth frequency is determined by the setting of time-base controls on the front panel of the scope. One of these is marked "coarse frequency" and the other is "fine frequency." The coarse frequency control, which may have a range from a few cycles to 50,000 cycles, is used to set the horizontal sweep to its approximate frequency. The fine frequency control, calibrated with a scale reading from zero to 100, is used for more precise adjustment. In using these controls, it is helpful to know the frequency of the voltage being examined. Thus, if the input signal frequency is 600 Hz, and you want to see three complete cycles on the screen, you would set the coarse control to one-third of the input frequency, or 200 Hz. Adjustment of the fine frequency control would then permit sine waves to be reproduced on the screen. Two cycles could be obtained by setting the frequency controls for a 300-Hz sweep.

Synchronization

The sawtooth voltage used for horizontal sweep is produced by a sawtooth oscillator, also known as a time-base oscillator or time-base generator. This oscillator is a free-running type, and its basic frequency is determined by the values of the components used in the oscillator circuit. In its free-running condition, the output of the time-base oscillator is not absolutely stable. Without some means of frequency control, the waveform display on the screen will drift back and forth. To make sure the oscillator will remain in step with the displayed signal, some form of oscillator synchronization is required.

Sync Signal Selector

For the most part, the sync signal used in typical oscilloscopes is a sine wave, although other types of AC waveforms can be used. The sync voltage source is selected by a front panel control known as the sync selector. On a representative scope the control can be set in any one of three different positions—external, internal, and line frequency. In the external position any available sync signal can be applied to the

scope through a terminal on the front panel. When the sync selector is set on internal a small portion of the vertical input signal is tapped off and used to control the frequency of horizontal sweep. Thus, if you are examining a sine wave, or any other waveform for that matter, and have connected this voltage to the input of the scope, a small portion of this signal is used to trigger the horizontal sweep oscillator. With the sync signal selector in the line-voltage position, part of the 60-Hz line voltage in the scope is tapped off and used.

The amount of sync voltage applied to the sweep oscillator is governed by another control on the front of the scope. This control, marked sync signal amplitude, should always be set as close to its zero position as possible, or to the minimum position which will lock in the pattern on the screen. Excessive sync voltage will cause erratic operation of the sweep oscillator and may distort the waveform you want to see.

The velocity of the electron beam in the CRT, as it moves from the cathode toward the screen, makes it necessary to use fairly high potentials to deflect the beam. Thus, amplifiers are used for both the vertical and the horizontal deflection plates. The output of the sweep oscillator is fed into a horizontal deflection amplifier, and its gain is controlled by a front panel potentiometer, known as the horizontal gain control. Similarly, the vertical input is followed by an amplifier, and its gain is determined by the setting of a potentiometer located on the front panel. Known as the vertical gain or V-gain control, it is used to adjust the amplitude of the signal appearing on the screen of the scope.

Looking at the Scope

Fig. 7-18 is a drawing of a typical scope front panel. Not all scopes look like this, of course. For example, this drawing shows binding posts for the vertical and horizontal input. Other scopes may use coaxial connectors instead. In addition, the sync selector on many scopes offers a choice of either positive or negative sync, which simply means the sync signal can be reversed in polarity for more stable control of the horizontal sweep oscillator. Starting at the top left-hand side we have the intensity control. The on-off switch is usually part of this control, although on some scopes you may find a separate toggle switch. Over at the top right-hand side we

have the focus control. Back on the left-hand side, the next control is marked "horiz position." On some scopes this control may be labeled X position, H position, or horizontal centering. Moving down we come to the "horiz amplifier" control. This may also be marked X gain, H gain, or horizontal amp.

The vertical input terminals are shown at the lower left. You may find these marked Y signal input, V, vert. input, or vert. amp. In the center of the control panel you will see the sync selector control. This may also be marked as the sync signal selector, synchronizing selector, timing sync,

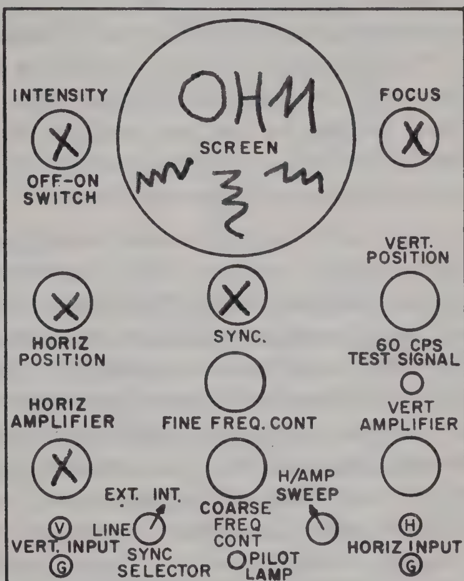


Fig. 7-18. Controls on the front panel of a scope may have names other than shown here and may also be positioned differently.

or synchronizing. The sync selector shown has three possible positions—line, external, and internal. Some scopes have additional positions for both positive and negative internal and external sync. In the center of the scope panel, directly under the CRT, is the sync control. This could also be marked as sync signal amplitude, sync signal, sweep sync, or locking. Directly below is the fine frequency control, which may be labeled sweep vernier frequency, or freq. vernier. The coarse frequency control hides under other identification such as sweep range, freq. range, or range. Over at the right-

hand side of the panel, the vertical position control is also called Y position or vertical centering. Sometimes just the word centering is used. Moving down to the vertical amplifier control, this may be also identified as V-gain, Y-gain, vert. gain, vert. amp, or Y-axis gain.

Located between the vertical position and vertical amplifier controls is a terminal marked "60-cps test signal." This terminal is connected to a 60-cycle source inside the scope, generally a low-voltage point such as a filament winding. The advantage of the 60-cps test signal is that it provides a fixed-frequency sine-wave which can be used as a signal amplitude reference to determine the peak-to-peak voltage value of the input signal. The horizontal input terminals at the bottom of the scope panel are also known as X signal input, H, or hor. input. The final control is the one marked H/amp sweep. Sometimes the letter H is omitted and the control is just identified as sweep/amp or it may be sweep/H.

You may find controls on a scope other than the ones we have described. For example, you may come across a Z axis input for modulating the intensity of the CRT beam. You may find a special switch just for turning the beam on or off, while all other circuits in the scope remain operative. But basically, the scope will have the controls described. The large number of controls on a scope and the use of different names for each control by the various manufacturers sometimes make a scope look bewildering. And, even if a scope should happen to use controls identified exactly as we have shown them in Fig. 7-18, they may be positioned differently. The horizontal position control might be on the right instead of the left. The positions of the vertical and horizontal amplifier controls may be transposed. Generally, though, vertical input is at the left; horizontal input is at the right. If you know how a scope works, and if you understand the purpose of each control, it won't take you very long to make practical use of the instrument.

Scope Circuits

Fortunately, the number of circuits in most scopes is limited —a vertical amplifier, a horizontal amplifier, a sweep oscillator, and a power supply (see block diagram, Fig. 7-19). We're going to begin with the sweep oscillator, but will call it by its more dignified name—a time-base circuit.

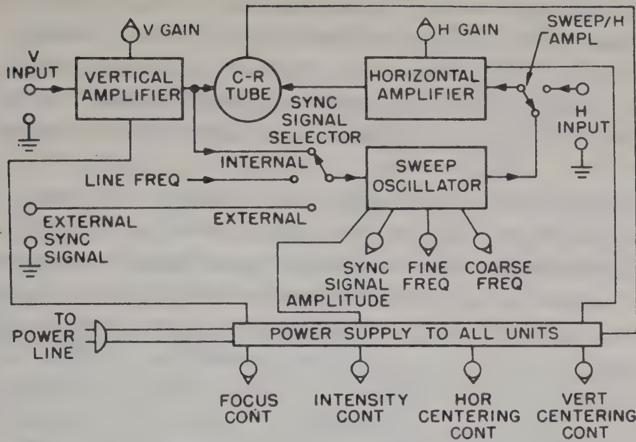


Fig. 7-19. Block diagram of a typical oscilloscope.

Time-Base Circuits

The job of the time-base circuit is to produce a voltage which will sweep the cathode-ray electron beam horizontally, thus producing a line of light across the face of the CRT. The voltage waveform produced by the time-base oscillator is a sawtooth, generated by charging and discharging a capacitor. To see how a capacitor can produce a sawtooth waveform, look at Fig. 7-20. The ascending line is the charge curve. If the capacitor is discharged through a resistor, we will get a

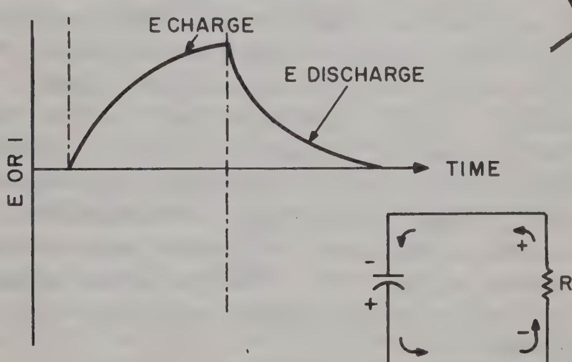


Fig. 7-20. Charge and discharge curves of a capacitor. The slope of the discharge curve depends on the values of R and C. Circuit shows charging current.

sloping discharge curve. However, we can get closer to a true sawtooth by discharging the capacitor more rapidly, as shown in Fig. 7-21. The base line on which we show the capacitor charge and discharge is plotted against time. It takes time to charge the capacitor; it takes time to discharge it.

If we assume that, originally, the cathode ray beam was positioned by the horizontal centering control so that the electron beam hit the left side of the screen (looking at the screen), then the ascending curve of the sawtooth would move the beam across the screen to the right-hand side. The extreme right-hand position on the scope screen would correspond to the maximum point on the capacitor charge curve. At this time, however, we short our capacitor and, since the voltage drops to zero, the CRT beam moves back to its starting point. We have produced two separate actions: the forward sweep of the

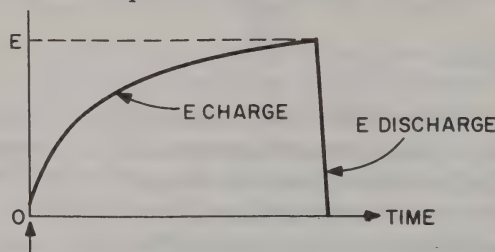


Fig. 7-21. The slope of the discharge line becomes steep and straight when the capacitor is discharged through a conductor.

CRT beam, and its return or retrace. The forward sweep is the action that takes the longer amount of time and actually is the amount of time required to charge the capacitor. The return trace or return sweep takes place quite rapidly.

The difficulty with our sawtooth is that it isn't as linear as it should be. In fact, it has quite a bend in it. Matters can be improved, though, by not waiting until the capacitor is fully charged, rather we discharge it at a somewhat earlier time. The effect of this action is to reduce the sawtooth amplitude as shown in Fig. 7-22. What we give up in amplitude here can be made up in the amplifier which follows the time-base generator.

The Relaxation Gas-Tube Oscillator

What we need now is a circuit that will permit us to charge

and discharge a capacitor by electronic means. This can be done with the gas-tube circuit shown in Fig. 7-23. Known as a relaxation oscillator, the circuit consists of capacitor C, gas-tube V1, and resistors R1 and R2. A gas-tube is nothing more than a switching device. When the voltage between the plate and cathode of the tube is high enough, the tube will fire—that is, the tube will conduct. If the voltage between plate and cathode of the gas tube falls below a certain amount, the tube stops conducting. Thus, the tube can be made to act like an open circuit or a short circuit.

Let's see what happens when this circuit is turned on. The gas tube and capacitor C are in parallel with each other and in parallel with the battery (representing the power supply). With the circuit on, current will flow through the capacitor and resistor R2, producing a voltage drop across the resistor. The voltage across the gas tube is equal to the battery or the supply voltage minus the voltage drop across R2, not enough at this time to cause the gas tube to conduct. Therefore, the tube is in its open circuit condition. As the capacitor charges it draws less and less current, gradually reducing the voltage drop across R2. Thus, the voltage on the plate of the gas tube increases, and when it becomes high enough the gas tube fires. In this condition the gas tube is like a short across the capacitor, so the capacitor discharges quite rapidly through the gas tube.

The large amount of current drawn through R2 during conduction of the gas tube produces a large voltage drop across the resistor, so the voltage available to the plate of the tube drops to a low value. Therefore, it stops conducting and the capacitor starts charging once again. If the gas tube is made to conduct earlier, we then get more waves per second. Hence, by changing the bias in the grid circuit we can control the number of times the capacitor charges and discharges per second, or the frequency of this sawtooth generator.

Time-Base Generator

The schematic in Fig. 7-24 shows the function of time-base controls. In the plate circuit there is a switch which selects any one of a number of different capacitors—the coarse frequency control—and a potentiometer, the fine or vernier frequency control. Sync voltage is applied to the grid through a

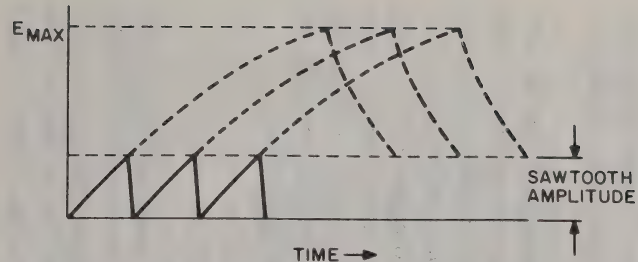


Fig. 7-22. By discharging the capacitor long before it becomes fully charged, we can produce a more linear sawtooth waveform.

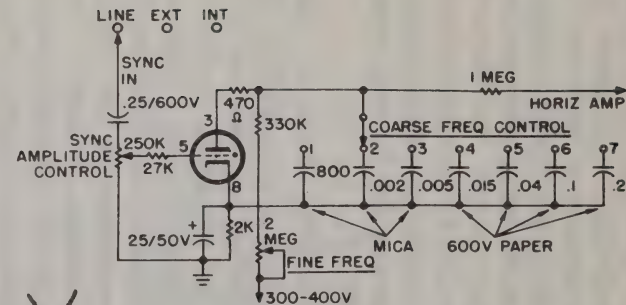


Fig. 7-24. Gas-tube time-base circuit.

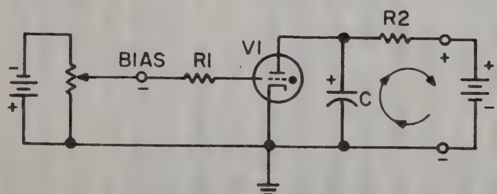


Fig. 7-23. Basic gas-tube relaxation oscillator circuit.

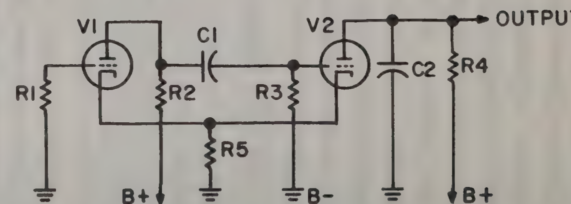


Fig. 7-25. Time-base using a cathode-coupled multivibrator.

signal selector switch, offering a choice of line, internal, or external sync. The potentiometer in the grid circuit controls sync voltage amplitude.

A vacuum tube can be used as a time-base generator instead of a gas tube. The circuit in Fig. 7-25 is so arranged that V1 and V2 alternate between conduction and cutoff. When V2 conducts, V1 is off. When V1 conducts, V2 is off. When V2 is cut off, C2 charges. When V2 conducts, C2 will discharge through the tube. This charging and discharging action of C2 produces a sawtooth waveform.

Horizontal Amplifier Circuit

Since the output of the time-base generator is usually too weak to provide adequate deflection of the CRT beam, it must be amplified. For this purpose most scopes use a horizontal

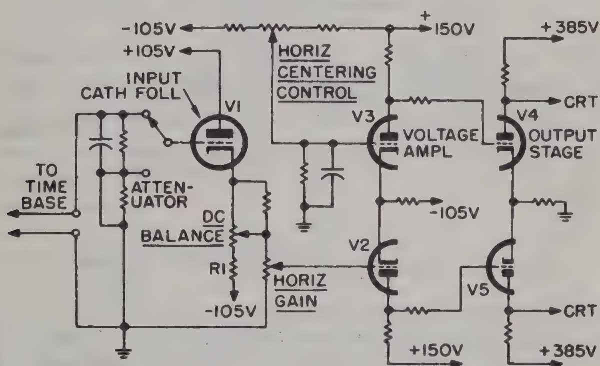


Fig. 7-26. A basic horizontal amplifier circuit.

amplifier, which also amplifies an external signal connected to the Y or horizontal input terminals if necessary. Fig. 7-26 shows a representative horizontal amplifier circuit. In some scopes a step attenuator is used to reduce the amount of signal input to the first amplifier tube without altering it in any other way. The horizontal gain control also varies the input signal, but since it follows the first stage distortion can occur if the first stage is overloaded.

In Fig. 7-26 the output of cathode follower V1 is taken from the DC balance control. The plate of V1 is tied to +105 volts and the cathode is returned to -105 volts. Thus, the cathode follower tube, the DC balance potentiometer, and resistor R1 form a voltage divider. Somewhere on that voltage divider we

have zero volts. The DC balance control is adjusted so that the arm of the control is as close to that zero-voltage point as possible. Thus, in the absence of a signal, the voltage put on the grid of amplifier tube V2 is zero.

The output of V1 is fed to amplifier tube V2 through the horizontal gain control. The adjustment of this control determines the amount of sweep, therefore, the length of the horizontal sweep line on the CRT screen. V2 is cathode-coupled to amplifier tube V3, and the outputs of V2 and V3 are direct coupled to V4 and V5. The purpose of V2-V3 circuitry is to supply a pair of out-of-phase signals to V4 and V5. Thus, the outputs of V4 and V5 are out of phase, providing the equivalent of push-pull operation without the use of a push-pull transformer. The advantage here is that as one horizontal deflection plate

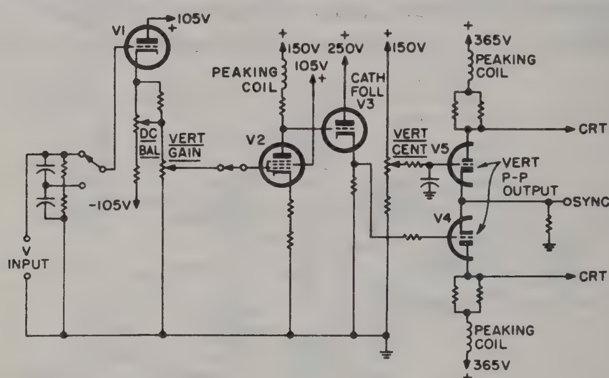


Fig. 7-27. A typical vertical amplifier circuit. Peaking coils are used to extend the frequency response of the amplifier.

is made positive the other horizontal deflection plate is made negative.

The Vertical Amplifier

The vertical amplifier circuit in Fig. 7-27 also uses a step attenuator at the input of cathode-follower V1. A DC balance control, whose function is the same as in the horizontal amplifier, is located in the cathode circuit. The signal is amplified by V2 and the output is used to drive another cathode follower, V3. Notice the peaking coil in the plate circuit of V2. The purpose of this coil is to extend the frequency response of this stage. V4 and V5 are push-pull output tubes. Part of the

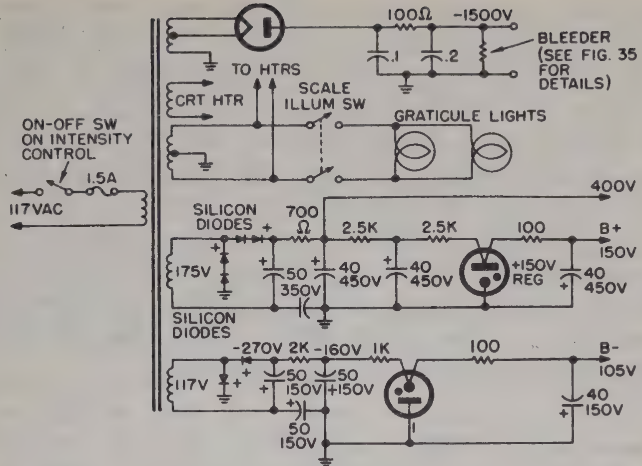


Fig. 7-28. A scope power supply is really three supplies using a single transformer.

output is tapped off and used as a synchronizing voltage when the scope's sync selector control is set to internal sync. In the plate circuits of V4 and V5 there are additional peaking coils used to extend the frequency response of the push-pull output stage.

DC Operating Voltages

It is usual practice to make the cathode and the control grid of the CRT highly negative. The usual CRT voltages are from one to two kilovolts, but higher voltages are used. The CRT requires little current, generally 1 milliampere or less. The

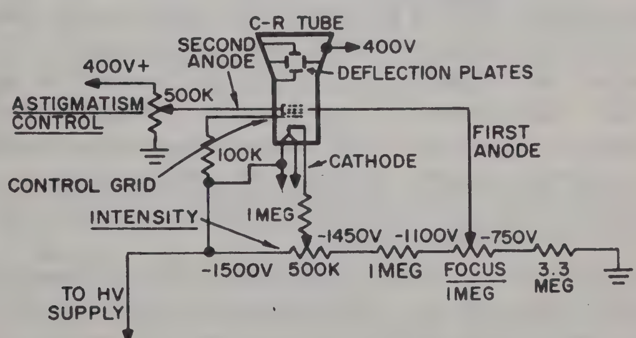


Fig. 7-29. CRT operating voltages are taken from a bleeder across the high-voltage supply.

vertical and horizontal amplifiers in the scope require low B +, ranging from 100 to about 300 volts. The total plate and screen requirements may be 10 milliamperes or more per tube. Thus, we have two basic requirements for the scope's power supply: high voltage and very low current, moderate voltage and much higher current. The high-voltage supply is usually a half-wave type followed by a simple R-C filter. The low-voltage supply is either a full-wave rectifier or a full-wave voltage-doubler type. A vacuum-tube rectifier is used for the high-voltage supply while either tubes or silicon diodes are used for the low-voltage supply. The filter for the low-voltage supply can be an R-C or L-C type.

The Power Supply Circuit

Fig. 7-28 shows a typical scope power supply circuit. A single power transformer is used, but you can see there are a number of secondary windings for the different voltage requirements. Starting on the primary side we have the on-off switch and a fuse. The switch is located on the intensity control. The fuse may be a plug-in type and is generally located at the back of the scope.

In this circuit a half-wave diode supply gives us 1500 volts across the output filter capacitor. Fig. 7-29 shows the details of the high-voltage bleeder. Ground on the bleeder is zero, and as we move along it the voltage becomes more and more negative. From the position of the CRT cathode and control grid connections you can see that the control grid of the CRT is tied on to the more negative portion of the bleeder, making the control grid negative with respect to the cathode. The voltage between control grid and cathode can be changed by varying the intensity control, which changes the bias on the CRT. Consequently, the intensity control varies the brightness of the trace on the scope screen from completely off to extremely bright. The normal position of the intensity control should be for the minimum amount of brightness that will give a good, viewable trace.

Another potentiometer that is part of the high-voltage bleeder is the focus control, since the focusing anode is also the first anode. It may seem odd that there is a negative voltage on this anode, but since the anode voltage is much less negative than the cathode, the effect is just the same as if we had put a posi-

tive voltage on it. This anode, then, will attract electrons from the cathode and help move them along to the screen.

A word of caution about the CRT anode: This is the maximum high-voltage point in the CRT. While a shock from this high voltage may not be lethal, it can be unpleasant. The natural reaction to a shock is quick withdrawal of fingers, but if there is something in the way the resulting bruise may be far more serious than the shock. Incidentally, the fact that the high voltage is negative makes no difference. Polarity doesn't count when you accidentally touch a high-voltage point.

Fig. 7-29 shows that one side of the CRT filament is also connected to the high-voltage bus. Since there is no current flow through the 100K grid return resistor, the filament and control grid are at the same potential. If we allowed the filament to "float," the high potential that would exist between filament and cathode might cause a breakdown. This bias on the CRT ranges from near zero to minus two hundred volts (approximately).

The second or accelerating anode is connected to a potentiometer known as the astigmatism control. As shown in the schematic, one end of this control is grounded. But ground is also the most positive point on the bleeder network. In this circuit there is a potential difference of about 1500 volts between ground and cathode, the exact amount depending on the positioning of the intensity control at any particular time Thus, as far as the accelerating or second anode is concerned, it is 1500 volts plus with respect to the cathode when the astigmatism control is at its ground end. The astigmatism control is also connected to 400 volts B+. By connecting the pot this way, the two voltage supplies, high-voltage and low, are wired in series aiding. As a result, when the astigmatism control is at one end, the second anode will have 1500 volts plus 400 volts or a total of 1,900 volts on it.

The Low Voltage Supply

There are two low-voltage power supplies in Fig. 7-28. One supplies B+, the other B-. The B+ supply is a full-wave voltage doubler type using an R-C filter. 400 volts B+ is tapped off the filter. Following the filter is a gas diode voltage regulator which helps maintain a constant output of 150 volts, regardless of minor fluctuations in the load. The other power supply is a full-wave voltage doubler type with a regulated negative output.

CHAPTER 8

Using the Oscilloscope

A scope can look quite complicated to those who have not used it. For one thing, it has a larger number of controls than other instruments. And the patterns produced by the scope can be confusing, especially if the relationship between the controls is not understood or if there is no understanding of what they are supposed to do. The thing to do when you get a scope for the first time is to become acquainted with its controls and learn what each is supposed to do. It's a great temptation to see the variety of waveforms that may be obtained, but you must know how the scope works and why it works to be able to use it intelligently. Waveforms may look interesting, but they won't mean a thing unless you understand how you obtained them.

Use of the Controls

The on-off switch is probably located on the intensity control. By adjusting it back and forth you can readily see its effect on the illumination. Set the sync selector control to internal sync. Set the coarse and fine frequency controls to approximately center position. Adjust the horizontal gain control until you have a horizontal line on the screen; rotate the control and note its effect on the line length. Now adjust the focus control for best possible focus—that is, try making the horizontal sweep line as sharp as possible. Adjust the intensity control and note its effect on focus.

If the line across the screen seems to have tiny waves or ripples in it, turn the vertical gain control to its zero position, the maximum counterclockwise setting. Connect a small piece of bare wire to the vertical input terminal and put your finger on it, then slowly turn the vertical gain control. You should see some type of waveform on the screen. It probably

will resemble a distorted or jagged sine wave. Rotate the vertical gain control and notice that you can make the amplitude as large or as small as you wish.

Now adjust the sync signal amplitude control until it is in its zero position or maximum counterclockwise setting. Turn the coarse frequency control until there are three complete wave cycles on the screen. These waves may be running back and forth. Advance the sync amplitude control and notice how the setting of this control locks the waveform in place. Keep turning the sync control and you will see that the effect of an excessive sync signal is to distort the pattern. Return the sync signal amplitude control to the minimum position at which it locks in the pattern. Set the coarse frequency control for two complete cycles and then for one complete cycle of the wave. You will find that adjusting the fine frequency control will help you get the number of waves you want.

Connect an audio generator to the vertical input terminals. If you do not have an audio generator, use a filament transformer. Your scope may have a terminal marked "60 cps" or "test signal." This is a 60-Hz (cycle) voltage source and you can use it by connecting a wire between this terminal and the vertical input terminal. Adjust the frequency controls until you have three complete waveforms on the screen. Readjust the focus and intensity controls and notice the effect both have on the brightness of the waveform and its sharpness. Advance the sync signal amplitude control and notice again that it will distort or tear the waveform if advanced too far. Rotate the vertical gain control and observe how you can make the pattern larger or smaller. Also vary the horizontal gain control to see if you can bring the waveform close together or spread wide apart. If you turn the sync signal selector control to external sync, the waveform probably will run back and forth across the CRT screen.

It is possible to use an external sine-wave sweep, as described earlier, by connecting a source of sine-wave voltage to the H input terminals and turning the sweep/H amplifier control to the H input position. When using such sweep, it is possible for the return trace to become visible. Notice the difference between the sawtooth and the sine-wave sweep. With a sawtooth, the time of retrace is extremely short—so short, in fact, that the return movement of the beam to its starting position may not produce a return trace of light. With external

sine-wave sweep, however, the forward and return movement of the beam is at the same rate. Consequently, it is entirely possible to see the return trace unless it is superimposed directly on the forward trace. Some scopes come equipped with a phasing control. Basically, it is just a phase-shifting network to make sure that both the forward and reverse patterns coincide. Fig. 8-1 shows the effects of proper and improper phasing.

Good Scope Practices

There are a few do's and don'ts regarding the care and use of a scope. It is an unusual instrument, and even inexpensive types can supply a large amount of information if properly handled and properly used.

1. Do not operate the scope with its cabinet removed. Not only is there danger of damage to the CRT, but stray magnetic fields may affect the pattern on the screen. The metal cabinet protects the scope and also acts as a shield.

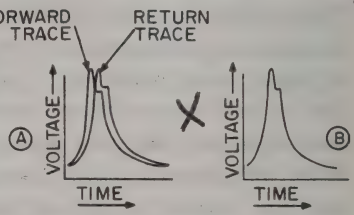


Fig. 8-1. Waveform drawings showing effect of the phasing control.

2. It is quite customary to have the scope working all day. There is nothing wrong with this; scopes are intended to be servicing and laboratory workhorses. But if you are not using the scope, turn down the intensity control (or the beam-off switch, if there is one) so there is no trace on the screen. The glowing pilot light will act as a reminder that the scope is on.

3. Tubes used in scopes, such as the vertical and horizontal amplifiers, do get weak. Don't depend on advancing the H and V gain controls. Replace the tubes when they become weak.

4. Keep the scope away from anything generating a strong magnetic field, such as a heavy-duty isolation transformer. The fields of such devices may be strong enough to penetrate the scope's cabinet and make it impossible to get a perfectly straight horizontal trace.

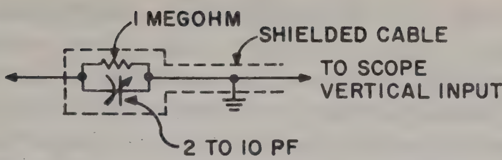


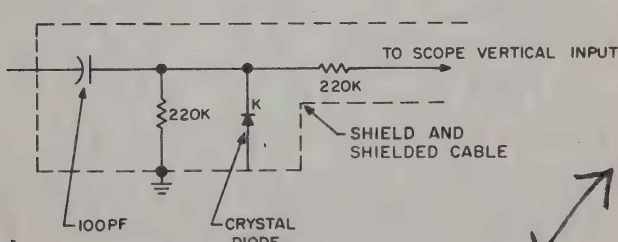
Fig. 8-2. Low-capacitance probe schematic.

5. Make sure you stay within the voltage input limitations of your scope.

Scope Probes

Just several inches of wire connected to a scope's vertical input terminal may be enough to produce a pattern on the screen. To avoid such pickup good scope practice calls for the use of a shielded input lead. The "hot" lead or center conductor of the shielded lead is connected to the vertical input terminals while the shield braid is attached to the ground connection. Some scopes are special connectors so that the "hot" and "ground" connections are made at the same time. The disadvantage of shielded cable is that it adds capacitance across the input. This capacitance can distort the signal input, especially in the higher frequency ranges. To avoid this difficulty, a special probe, known as a low-capacitance probe, is used. Fig. 8-2 shows the circuit of such a probe. It consists of a 1 meg resistor shunted by a small variable capacitor having a range of approximately 2 to 10 picofarads. While the probe does cause signal loss, it can be overcome by advancing the vertical gain control on the scope panel.

Another type of probe is a demodulator (or detector) probe (also known as an RF probe). The circuit is shown in Fig. 8-3. A probe of this type may be used in testing modulated RF signals, such as the signals preceding the second detector in radio and television receivers. The diode in the demodula-



RF Probe

Fig. 8-3. Schematic of a demodulator scope probe.

ISOLATION Probe
Low C Probe

tor probe works as a simple detector. The frequency of the detected signal is much lower than that of the modulated signal and can be fed to the vertical amplifier in the scope. If (without the probe) you check circuits in radio receivers prior to the second detector, the display on the scope screen will be distorted, or quite possibly you may not see anything at all. Demodulator probe cable should have as low a capacitance as possible. It is advisable to use cable designed for this purpose. Probe cables should never be any longer than absolutely necessary.

Still another accessory used with the scope is the isolation probe. As shown in Fig. 8-4 this is a very simple type and consists of a 1 meg resistor inserted in series with the hot lead of the probe cable. The purpose of the probe, as its name suggests, is to isolate the scope's input circuit from

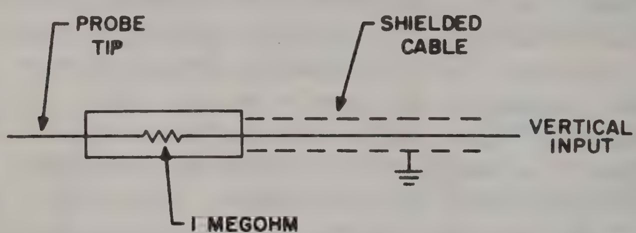


Fig. 8-4. An isolation probe is used to isolate the circuit under test from the scope input.

the circuit being checked. This is important where the circuit being checked must not be loaded or altered if the waveform it produces is to be observed correctly. Some technicians attach a 1 meg resistor to their demodulator and low-capacitance probes to get additional isolation, but this precaution isn't necessary.

Quite often there will be both DC and AC at the point in the circuit being tested. A small capacitor connected between the scope's vertical input and the test point can be used to block the DC. The higher the frequency at the check point, the lower the capacitor value which may be used. In some cases, just putting the point of the test probe near the check point is sufficient; the capacitance existing between the check point and the probe tip may be enough to couple sufficient signal into the probe. In any event, it is always better to use the lowest value of capacitance that will permit sufficient signal to pass.

Measuring AC Voltages Obdecall

The scope is not only useful for observing all kinds of waveshapes, but it can also be used to measure their actual values. This is of considerable advantage, for meters generally are suitable only when the waveforms to be measured are sinusoidal. We can measure the peak-to-peak amplitude of any type of waveform by using a sine wave voltage as our calibration source. To calibrate the scope we need a source of AC voltage, such as the power line. In addition we need the help of an AC voltmeter, and, of course, the more accurate the meter, the more accurate our calibration will be. Finally, we need a linear potentiometer having a 25,000-ohm range.

Fig. 8-5 shows the setup to use in calibrating the scope.

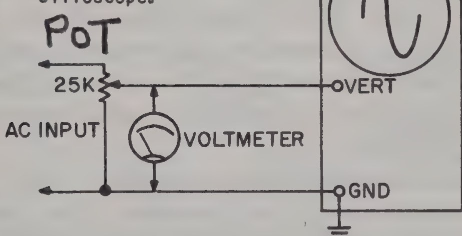


Fig. 8-5. Method of calibrating an oscilloscope.

The value of AC input voltage is determined by the setting of the potentiometer. The meter is shunted across the center arm of the pot and the ground terminal of the scope and reads the root-mean-square or rms value of the AC input voltage. However, since we are going to calibrate our scope in terms of peak-to-peak, not rms, we need to know the relationship between the two. Rms can be converted to peak-to-peak by multiplying the rms value by 2.82. Fig. 8-6 shows the relationships for various values of a sine wave. The peak value of a sine wave is 1.41 times the rms value. To get the peak-to-peak value we simply multiply the peak by 2. Typical power line voltage is usually 117 volts rms. To get the peak value, multiply 117 by 1.41 and we get 164.97 volts. To obtain the peak-to-peak value, 164.97 is multiplied by 2. This information can be used to calibrate the scope. Connect the signal source to the vertical input terminals, as shown in Fig. 8-7. This illustration shows the use of an ordinary filament trans-

GIVEN THIS VALUE	MULTIPLY BY THIS VALUE TO GET			
	AVERAGE	EFFECTIVE	PEAK	P-P
AVERAGE	—	1.11	1.57	1.274
EFFECTIVE	0.9	—	1.414	2.828
PEAK	0.637	0.707	—	2.0
P-P	0.3185	0.3535	0.50	—

Fig. 8-6. Relationships between the various values of a sine wave.

former as the calibrating voltage source. The input voltage is 6.3 volts rms. If this value is multiplied by 2.82 we will get the peak-to-peak value of the input, or 17.666 volts. We can call this 18 volts. Most scope graticules are marked off in squares. Adjust the vertical gain control until the waveform on the screen occupies 18 squares. Nine of these squares will be above the thick horizontal line or X-axis and nine will be below it.

Now each square on your scope represents 1 volt. Disconnect the filament transformer from the power line and then disconnect it from the V and G terminals of the scope. Do not touch any of the controls on the scope. You can now connect a voltage source to the V and G input of your scope and measure its voltage. There is a limitation to this, since your scope, as presently calibrated, may not be able to measure more than 50 to 100 volts peak-to-peak, depending on how many vertical squares you have on the graticule. But you can always recalibrate the scope using a higher AC input voltage.

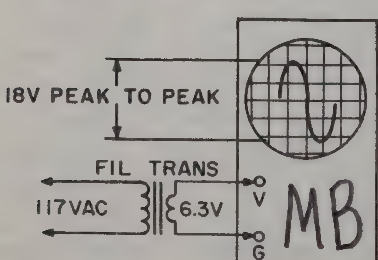


Fig. 8-7. A 6.3-volt filament transformer can be used to calibrate a scope.

Determining Vertical Deflection Polarity

Some scope patterns may show a distorted upper or lower half, and often the trouble can't be traced to its source unless the input polarity of the scope is known. To determine the polarity of deflection, turn off the horizontal sweep and reduce the intensity to the point where the spot of light barely can be seen and adjust the focus control to a position that causes the spot to be as large as possible. Set the vertical gain control to its maximum. Connect short pieces of insulated wire to the vertical input terminals. Touch the two together momentarily, then touch them to the terminals of a 4 to 6 volt battery. The spot will jump either up or down, then return slowly. It jumps because the battery voltage causes the scope's input DC blocking capacitor to charge, then slowly discharge. Touch the wires together to completely discharge the capacitor, then reverse the battery connections to the input. The spot will now jump in the opposite direction. Notice

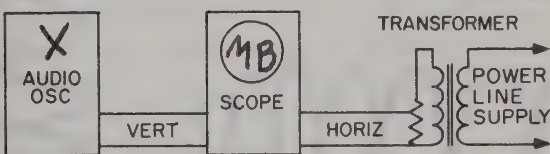


Fig. 8-8. Scope setup for frequency comparison.

the battery polarity that makes the spot jump up. If the spot jumps up when the positive battery terminal is touched to the hot terminal, the scope input is positive.

Frequency Comparison

A scope is a convenient means of comparing the frequency between two waveforms. The waveform of an unknown frequency may be applied to either the horizontal or vertical input and a waveform of adjustable frequency (an audio generator, for example) is applied to the other input. If an adjustable frequency source is not available, a small power line voltage may be used when the unknown is a multiple or a simple fraction of the power line frequency. In Fig. 8-8 an audio oscillator is connected to the vertical input and a sine-wave voltage connected to the horizontal input. We can get this sine-wave voltage from the power line by using a step-down trans-

former, such as a filament transformer. The frequency at the H-input can be 60 Hz or line frequency. Alternatively, you could connect an audio generator to the H input and then set the dial on the audio generator for any desired frequency.

What sort of patterns will we see on the scope screen? That depends on the ratio of the two frequencies—that is, the vertical and horizontal input frequencies. If both frequencies are identical, you may see a circle on the screen. If the frequency is a two-to-one ratio, that is, if the vertical frequency is twice the horizontal frequency, you will have a pair of vertical ellipses, next to each other. Such waveforms are commonly called Lissajous figures. Since each pattern obtained is a

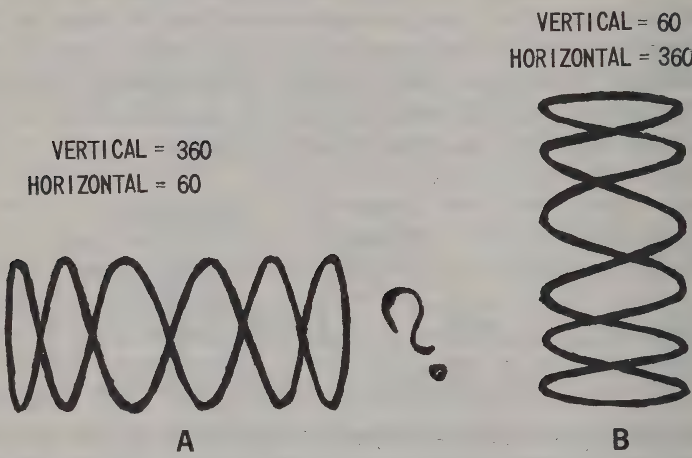


Fig. 8-9. Frequency comparison patterns called Lissajous figures.

definite ratio of one frequency to another, we can use this technique for calibrating an unknown frequency source. Thus, by connecting a calibrated audio generator to the H input and an unknown frequency to the V input, we can determine the unknown frequency by the pattern it produces. In Fig. 8-9A, for example, a 360-Hz signal is applied to the vertical and a 60-Hz to the horizontal input, a 6-to-1 vertical-to-horizontal ratio. The reverse ratio is shown in Fig. 8-9B. An unknown frequency may be determined by counting the number of waveform loops across the top and side. The ratio of the known and unknown frequencies is the same as the vertical-to-horizontal ratio of the Lissajous figure. This method may be used with ratios as high as 12 to 1.

CHAPTER 9

Servicing With the Oscilloscope

The VOM and VTVM are limited to sine-wave measurements. A distorted waveform measured by a VOM or VTVM will result in a movement of the meter pointer, but such readings are on a scale calibrated in rms volts. The value indicated by the pointer will be meaningless. The scope is the only instrument available to the technician which can both measure and display waveforms other than sine waves. And sine waves are not as common as you might think. Yes, the voltage delivered by the local power utility is a sine wave. But the signal received by a radio receiver or a TV set is not. An IF waveform is not. An audio signal is not, unless it is a test signal supplied by a generator (and this is not always true either). The sync voltages used in TV receivers are not sine waves. The input to a power supply is sinusoidal, and the power supply output may have a sine wave ripple, but that's about it. There are many uses for the scope—alignment, testing, and measuring are the most common applications. Now let's see what we can do about putting the scope to work.

Checking DC Voltages

Speaking of DC voltages, your first thought probably is the power supply, and quite correctly so. But we must remember that the DC of the power supply does not remain there. It is used throughout the receiver. The problem is that as we move away from the power supply we may tend to forget that certain points in a receiver should remain at DC potential. Suppose we consider a few of these.

Consider the screen grid circuit shown in Fig. 9-1. R1 is commonly referred to as the screen dropping resistor and C1 as the screen bypass. These are just names and they do not tell the whole story. R1 and C1 also can be considered as

additional filter units for the power supply. The big problem, though, is that one end of R1 is connected to a grid which is poking its wire structure right into a moving stream of electrons in a tube. Without C1 the screen grid behaves as a plate in competition with the plate of the tube. Ideally, the screen grid end of R1 should be at AC signal ground potential, and it will be if C1 is high enough in capacitance value.

How can we find out? Here's a simple way. Connect a test signal to the input and a scope to the output of an audio amplifer. Use the vertical input terminals of the scope with the sync control at its minimum setting and the coarse and fine frequency controls set to supply one or two sine-wave cycles on the screen. The generator audio output probably will be

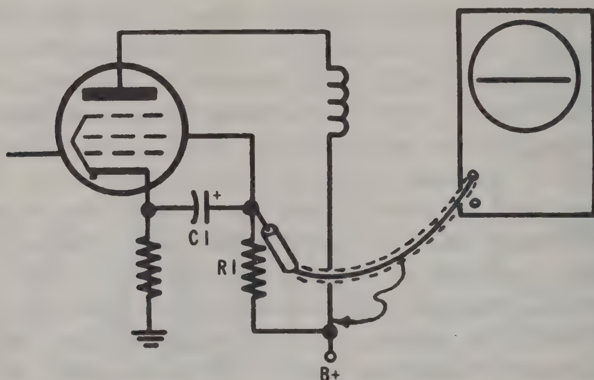


Fig. 9-1. Screen grid should be at signal ground potential. This test determines how effectively C1 filters the signal.

about 400 Hz. Now, disconnect the two instruments and connect the signal generator across the input of the tube—hot lead of the generator to the control grid, ground lead to chassis or cathode. Without touching the scope controls, connect the test leads across R1. All you should see is a straight line, if C1 is doing its job. If you get a ripple or any type of a waveform on the scope screen, try shunting C1 with a capacitor of equal capacitance value and equal voltage rating. Watch polarity.

A scope may fool you. You've got to remember that there is a substantial amount of amplification following the vertical input, so any hum voltages floating around can be picked up by the test leads. If the vertical gain control is cranked up near maximum, you may very well pick up a hum trace. This

may bother you, but of course you make allowance for it. In the first place, shielded coax should be used for test leads. If you are using unshielded leads you are practically begging for an interfering signal, but even with shielded wire you will not have protection all the way. If a coax connector is used at the scope input you have done the best you can at that end. On some scopes, though, the input is through a screw-type terminal. This means the coax must be stripped at the scope end to make a connection, and it is this stripped portion that can produce trouble with signal pickup. At the other end of the coax cable, an unshielded wire may connect to an alligator clip. Again, you have a pickup wire. Even if you use a test probe (and you should) the needle tip of the probe is unshielded. However, the use of a shielded probe and a coax connector is the best arrangement.

To get familiar with what a test cable and probe can do to

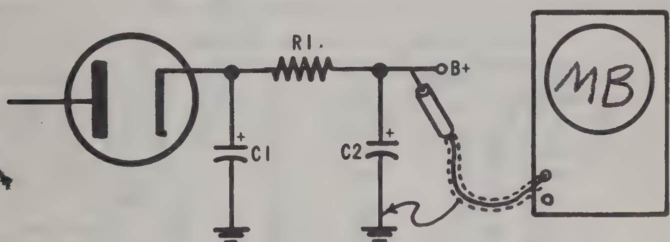


Fig. 9-2. Test for ripple in the power supply.

you, connect it to the vertical input and turn the vertical gain up to maximum. Put the test lead on the bench and see if there is any deviation from the horizontal line. Turn on some of your noise generators—your bench lights, fluorescent lights. Do you normally have a radio or TV turned on? Turn 'em on. Turn on your signal generator, too. For all you know it may be leaking like an electrical sieve. If, after you have done all this, the horizontal line across the face of the screen is straight, then you can be sure your equipment and lights are not producing any wiggles in your scope waveforms.

Checking Hum

Receiver hum, and this can exist in an AM, FM, or TV receiver, often means a defective filter in the power supply. In Fig. 9-2 we have a typical filter circuit. Using an isolation

probe, connect it as shown to the vertical input of the scope. Turn up the vertical gain. Now shunt C2 with an equivalent capacitor. If the hum persists and you see wiggles on the screen, try moving the test capacitor across C1. If the hum is caused by poor filtering in the supply, this should cure it. Incidentally, care must always be exercised in working across power supply voltages. However, you can be sure the power supply will remind you, given the opportunity.

There are several ways of identifying hum due to poor filtering in the power supply. If the filtering is bad enough, you'll be able to hear it, no matter what kind of set you are working on. In a TV receiver insufficient filtering in the power supply can result in hum modulation of the picture. There will be hum bars floating up and down in the picture. Actually,

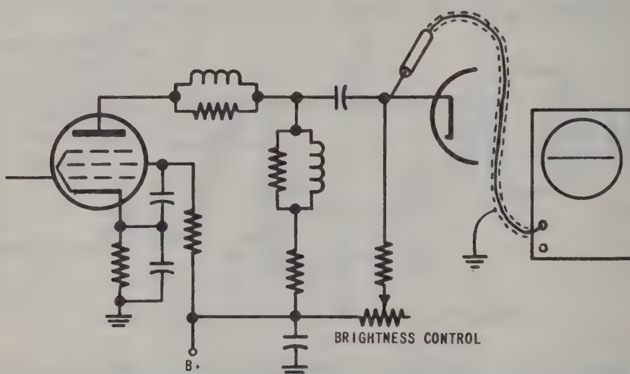


Fig. 9-3. Hum check at the picture tube input.

there are two types of hum you may see on the screen: One is that due to 60-Hz modulation perhaps caused by a cathode-to-heater leak. The other is power supply hum (ripply frequency of a half-wave supply is 60 Hz; that of a full-wave supply is 120 Hz).

Connect the scope's vertical input across the signal input of the picture tube, either cathode or control grid, as the case may be. Turn the vertical gain up a bit, and set the frequency control to some low value such as 30 Hz. Short the antenna leads or else set the tuner to an unused channel. Starting as shown in Fig. 9-3, move back stage by stage toward the front end until you pick up the stage producing the hum voltage. The hum voltage can be caused by heater-to-cathode leakage in any

one of the tubes from the front end up to the pix tube input, unless of course it is coming from the power supply.

Checking Cathode Filtering

Another place where we like to have nice, smooth DC is across the bias resistor of a tube, such as the one shown in Fig. 9-4. C1 is called the cathode bypass, but it is really a filter capacitor. If C1 is doing its job, the voltage drop across R1 should be DC. Connect the scope test leads across C1 as shown. Turn up the vertical gain control and see what happens. There should not be a signal voltage waveform on the scope. Turn up the gain of the signal generator. If the tube in Fig. 9-4 is an audio amplifier, use the audio signal output of your generator. If the capacitor is open, you'll see the signal waveform on the screen. The result will be some degeneration, a form of negative feedback. This may even improve the sound output, but there will be some small loss of gain, which usually can be overcome by turning up the receiver volume control a bit more. It is more serious if C1 is leaky. C1 is in parallel with R1, and R1 supplies bias. A leaky C1 can change that bias.

Checking Distortion

The distortion introduced in an amplifier stage may be determined with the setup in Fig. 9-5. Connect the scope to the output of the stage under test and a signal generator (with a sine-wave output) to the input. The output signal should be of the exact waveshape as the input, but of greater amplitude, of course. By using several frequency settings (if you have an audio oscillator), the precise degree of distortion at any specific frequency can be observed. At various points during the test it is a good idea to temporarily connect the scope to the output of the generator so that the waveshapes— amplifier input and output—can be compared accurately.

The waveform in Fig. 9-6A is free of distortion. But if, for example, the output of a particular stage produces a waveform similar to that in Fig. 9-6B, it may be that tube bias is too high or that plate or screen voltage is too low. The opposite condition(s) may exist if the output signal is similar to Fig. 9-6C. When both sine-wave peaks are clipped, as in

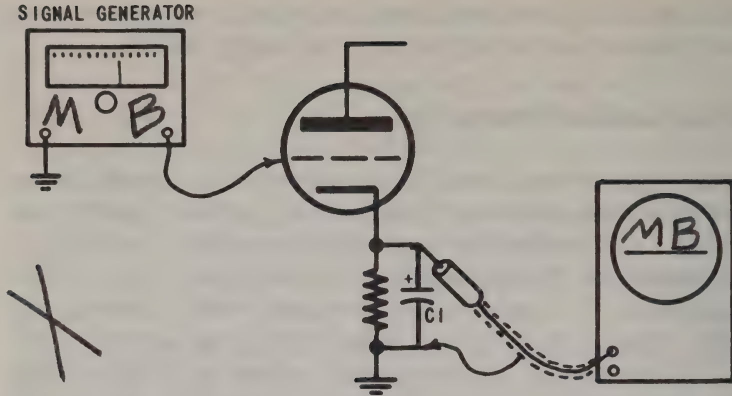


Fig. 9-4. Pure DC should appear across R1. There should be no signal indication on the scope screen.

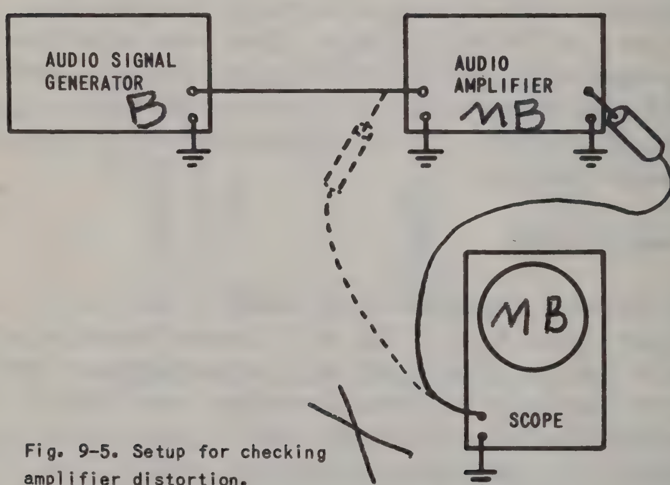


Fig. 9-5. Setup for checking amplifier distortion.

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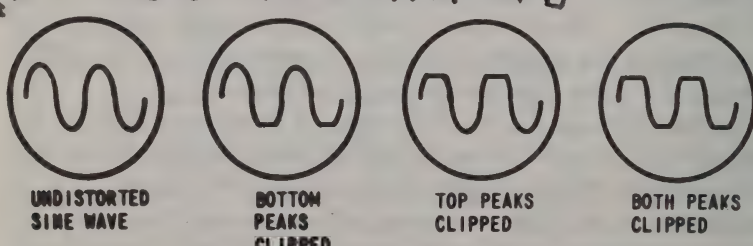


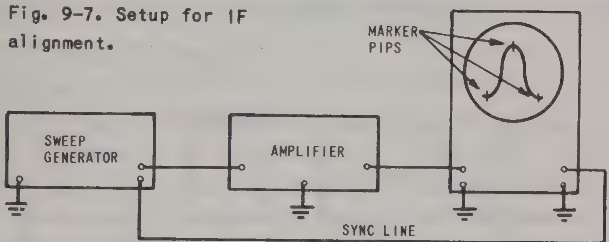
Fig. 9-6. Scope patterns showing distorted sine wave.

Fig. 9-6D, it probably is due to excessive signal input; a defect in the automatic gain control (AGC) or automatic volume control (AVC) circuit may cause the receiver to be inoperative, particularly when distortion occurs only when stronger signals are present

IF Alignment

A scope and sweep generator can be used when aligning the IF stages of an FM receiver, producing better results than with a meter and signal generator. With this method, the actual tuned-circuit response curves are traced out on the oscilloscope screen. The curve shown on the oscilloscope in Fig. 9-7 is typical. The peak of the curve must be exactly at the resting or center frequency around which the generator output is swept. To insure that the peak is at the resting frequency and that the bandpass characteristics are correct, marker signals must be used. Marker signals, properly injected into the circuit being aligned, will produce "pips" at points on the response curve corresponding to the frequencies of the marker signals as shown in Fig. 9-7. Any signal generator that is accurately calibrated and that can be tuned to produce an unmodulated signal at the desired frequencies may be used as a marker generator. Some special generators can supply several marker signals simultaneously. To obtain the three pips as shown in Fig. 9-7, it is necessary to inject marker signals at frequencies corresponding to the center, upper limit, and lower limit of the IF passband. But unless the bandpass characteristics are very critical, one marker signal at the center frequency is usually sufficient.

Fig. 9-7. Setup for IF alignment.



To align IF stages by this method, connect the vertical terminals of the oscilloscope across the grid resistor in the limiter stage. Connect the sweep generator to the grid of the

last IF stage. Fig. 9-7 shows the block diagram connections. Adjust the primary and secondary trimmers until the desired response curve is obtained on the screen.

Align the other IF stages by moving the signal generator input to the receiver, one stage at a time, back toward the mixer stage and by repeating the above procedure.

Discriminator and Ratio Detector Alignment

Fig. 9-8 shows the block diagram connections required for discriminator alignment. The two pips shown may be obtained by connecting two marker signals, at the upper- and lower-limit frequencies of the IF passband, in parallel with the sweep-generator input. Connect the vertical input of the oscilloscope across the audio output circuit of the discriminator. Connect the FM sweep generator to the grid circuit of the last limiter stage. Connect the sweep voltage of the FM generator

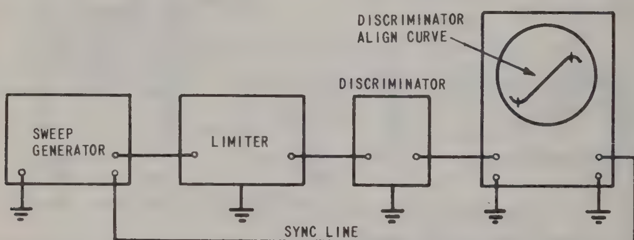


Fig. 9-8. Setup for discriminator alignment.

(sync line of Fig. 9-8) to the horizontal input of the oscilloscope.

If the discriminator is properly aligned, a sharply defined S curve will appear well-centered on the scope. A further aid to determine the linearity of the discriminator is a marker signal at the center of the IF passband. This marker will appear at the center of the S curve when the linearity is good. A raggedly shaped S curve indicates a poorly aligned primary circuit. Tune the primary of the discriminator input circuit until a smooth S curve (Fig. 9-8) of maximum amplitude is obtained. The secondary of the discriminator is tuned for maximum length of the linear portion of the S curve. If the marker signal is used, tuning should center the S curve on the marker pip.

When aligning receivers that use a ratio detector, connect the sweep generator to the grid of the last IF stage. Connect

the scope input to the audio output of the ratio detector. Proper alignment is indicated by the previously mentioned S curve (the same as for the discriminator), but there the similarity ends. If the secondary of the detector input transformer is detuned, the S curve will become the familiar bell curve (Fig. 9-7).

Start the alignment by detuning the secondary of the detector input transformer. This should result in a bell-shaped curve on the oscilloscope. Tune the primary for maximum amplitude of the bell curve.

Align the remaining IF stages, one at a time, moving towards the mixer. Then adjust the secondary of the detector transformer for the S curve. A marker signal, injected with the IF signal, is helpful in centering the S curve.

RF Alignment

The visual method can be used to align the RF, mixer, and oscillator stages of an FM receiver. Connect the vertical input of the oscilloscope across the limiter grid resistor and the sweep generator output to the antenna terminals of the receiver. The test setup is the same as that in Fig. 9-7, except for the point of sweep generator connection. Set the sweep generator and receiver to the same frequency near the high end of the receiver dial. This should be done with an accurately calibrated marker generator or frequency meter. The sweep generator should be adjusted to sweep at least twice the band width that the receiver is designed to pass to insure a display of the entire bandpass response curve. Adjust the oscillator trimmer (also the RF and mixer trimmers if used) for maximum amplitude of the response curve. Set the sweep generator and receiver to the same frequency near the low end of the receiver dial. Adjust the oscillator padder (also the RF and mixer padder if used) for a maximum response curve amplitude. Notice the amplitude of the response curve in the two preceding steps and repeat the high and low end alignment until no further increase can be obtained.

A final check of the receiver dial calibration and tracking should be made. This is done by checking the receiver at several frequencies throughout the tuning range of the band being aligned. Set the sweep and marker generators accurately at each of these frequencies and check the receiver's output on the scope. Calibration and tracking of the receiver is

checked by observing that the marker pip is in the same position on the response curve and that the curve is the same amplitude on the scope waveform at each of the check points.

TV Troubles

Series power supply arrangements in TV sets, such as the circuit shown in Fig. 9-9, are now fairly common. V1 is a beam power audio output tube. V2 could be a sync separator, or V2 and V3 could be a pair of IF amplifiers. Trouble with

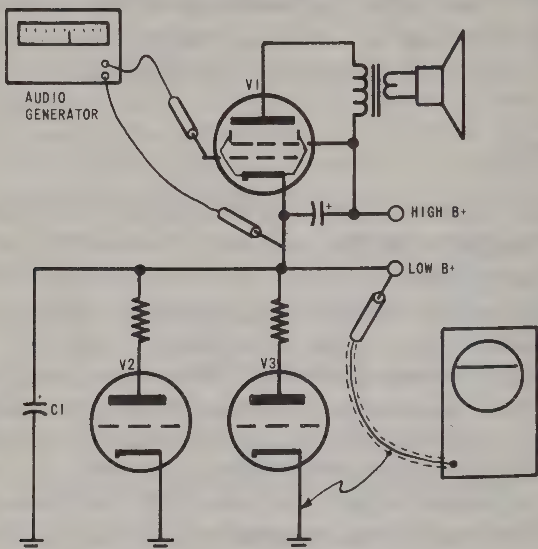


Fig. 9-9. C1 is very important in circuits using series or stacked tubes. If C1 is leaky, open or has insufficient capacitance, signal modulation of V2 and V3 will take place.

C1 in this circuit can lead to all sorts of odd-ball difficulties, since the current through V1 will modulate the currents flowing through V2 and V3. That big capacitor, C1, on the end of the low B-plus line is mighty important. Connect the scope cable from the low B-plus point to ground. Feed in a strong signal from an audio generator to the control grid of V1. Naturally, the receiver must be turned on. Look for a straight horizontal line across the scope, even with the vertical gain control turned up. If you get any sort of wiggle on the screen, try shunting C1 to see if you can make it go away.

Checking AGC Filters

Another location of filter trouble in a receiver—and it can be AM, FM, or TV—is the AGC bus. The voltage fed back to the controlled tubes is DC. It is actually a filtered rectified signal voltage. Check the AGC bus in the same way as you would check the filter of a power supply. The resistance and capacitance values in an AGC network, though, are a bit more critical than power supply filter values. In the AGC system we are concerned with the R-C time constant, for that decides whether the AGC is slow or fast acting. The best thing to do in AGC circuits is to replace components with parts having equivalent values. Don't go experimenting around. The manufacturer has already done that.

Troubles in the AGC line can result in TV picture flutter—that is, the picture will seem to fade in and out. This could be caused by an open AGC filter capacitor. Try shunting each of the AGC capacitors with an equivalent unit. If that doesn't help, look for some difficulty in the circuits that precede the video detector. (The video amplifier isn't AGC controlled.) Misalignment of the IF, or a defective bypass capacitor in the IF, can produce this trouble. Make sure the IF isn't overpeaked—that is, that it hasn't been aligned for a narrower bandpass to give more gain. If you don't want to bother realigning just to make sure, try shunting the primary and secondary of each IF transformer with a 5K resistor as a temporary expedient.

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Oscillation in the IF

Sometimes in fringe areas, technicians will overpeak the IFs deliberately to coax a bit more gain out of the set, with the theory that a miserable picture is better than no picture at all. If the receiver is then moved to a stronger signal area, the picture will be severely distorted. The same trouble can be caused by open screen bypass capacitors, shields which have been removed from IF transformers or which have been replaced hastily, with poor or no contact with the chassis. This can cause signal feedback, through magnetic or capacitive coupling, from one stage to some preceding stage. The result is an enormous increase in gain, a much narrower bandwidth, and a rippled, excessively black picture on the

screen. Using a sweep generator, feed in a signal at the IF frequency to each IF stage and observe the sweep pattern on the scope. Examine the sides of the waveform. If they are jagged, instead of being smooth, there is trouble in that IF stage.

Picture Nonlinearity

A nonlinear picture is one in which objects on the receiver screen seem distorted. The distortion may be horizontal, vertical, or an unhappy combination of both. Control adjustment to improve linearity depends on the receiver and on its age. Older type receivers have more controls for making linearity adjustments. Modern sets have eliminated some of them. Adjust whatever you can and whatever is available—vertical linearity and horizontal linearity. There may be an interaction between vertical and horizontal gain controls. Some receivers have "built-in" nonlinearity. They are manufactured for a price and the nonlinearity is part of the design. However, even with all these alibis at hand, it is possible for vertical and horizontal linearity to exist because of some defect in the vertical and horizontal amplifier circuits.

Don't try to make changes in the vertical and horizontal amplifier circuits to improve linearity by using a TV program as a test signal. It's much better to use the station test pattern. The trouble with this suggestion is that broadcast test patterns have become fewer and further between. And test patterns have a habit of going off the air at the most inconvenient times. You can use your scope to check linearity conveniently and comfortably. Fig. 9-10 shows a technique that can be used for the horizontal amplifier. A 5-ohm 10-watt resistor has been inserted in series with the horizontal deflection yoke coils. The voltage across the yoke coils has a trapezoidal waveshape, but the current flowing through them is a sawtooth. If this current flows through a resistor, the result will be a sawtooth voltage waveform across the resistor. We can connect the vertical input of the scope across the 5-ohm resistor, setting the coarse and fine frequency controls to produce several sawteeth on the scope.

Any changes you make in the horizontal oscillator circuit or horizontal amplifier will modify the pattern you see on the scope screen. For example you can use a resistance substitu-

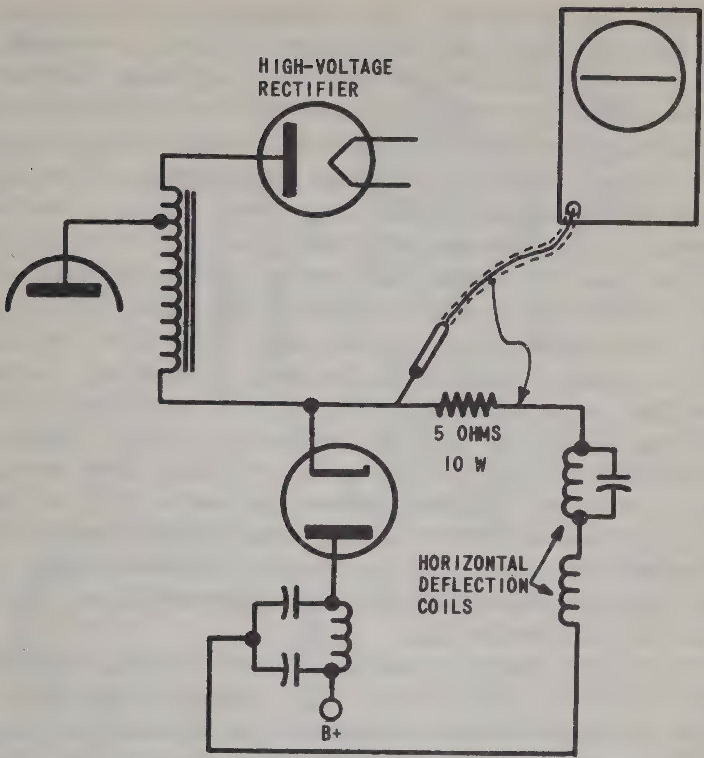

Fig. 9-10. Method of checking the horizontal sweep circuit for linearity. The voltage across the 5-ohm resistor should be a sawtooth.

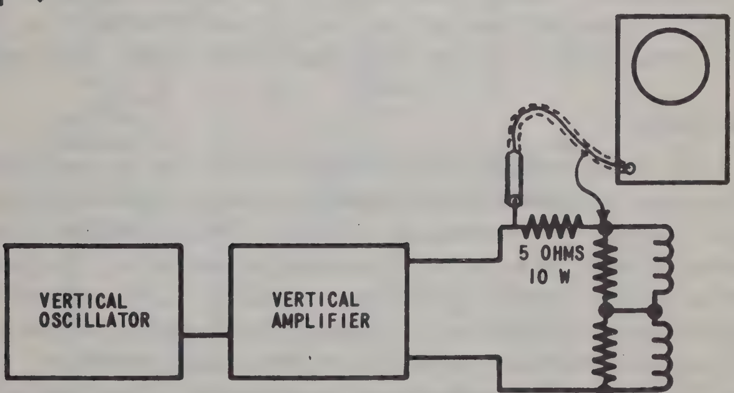

Fig. 9-11. Method for checking vertical sweep linearity. The voltage across the 5-ohm resistor should be a sawtooth.

tion box, and substitute it for resistors in these circuits to find the value which will help you get as close to a sawtooth as possible. Try changing the horizontal oscillator, horizontal output, and damper tubes. This doesn't mean these tubes are defective, but sometimes one tube will produce better linearity than another. Adjust any variable controls to see if any bring about an improvement. Sometimes, due to design, a variable control will be at the end of its travel, and as it moves toward its maximum resistance point you will notice a gradual improvement in the sawtooth waveform. The answer is obvious. Try a new control having a wider range. The same technique, and the same resistor, can be used in checking vertical linearity, as shown in Fig. 9-11. Don't make changes just for the sake of keeping busy. If you make a change, notice the direction in which the circuit wants you to go. Does increasing the value of a resistor improve the sawtooth? If so, keep adding resistance until the sawtooth starts getting worse again. Then back off until you get the optimum resistance value. You can follow the same technique with capacitors if you have a capacitor substitution box.

Various other problems can be solved with the scope connected as shown in Fig. 9-10 or Fig. 9-11. Defects in the yoke, or in the resistors (vertical windings) or the capacitor (horizontal winding), can produce ringing (vertical lines on the picture tube screen) or keystoning (trapezoidal raster). Other troubles include insufficient height or wiggling vertical or horizontal lines in the picture. Insufficient picture height can be caused by a wrong value resistor across the vertical windings. Horizontal foldover can be produced by a defect in the horizontal coils or wrong value capacitance of the shunt unit.

No Raster

Lack of high voltage in a TV receiver can be due to trouble anywhere from the horizontal oscillator on out to the high voltage rectifier. To locate the difficulty with the scope, three circuits must be considered: horizontal oscillator, horizontal amplifier, and high-voltage rectifier. Let's regard the horizontal amplifier as the midway point and try to learn if the trouble precedes or follows the horizontal amplifier. Fig. 9-12 shows how the scope should be connected. Since the horizontal sweep frequency is 15,750 Hz, set the scope frequency control to one-third of this, or approximately 5,250 Hz. Keep

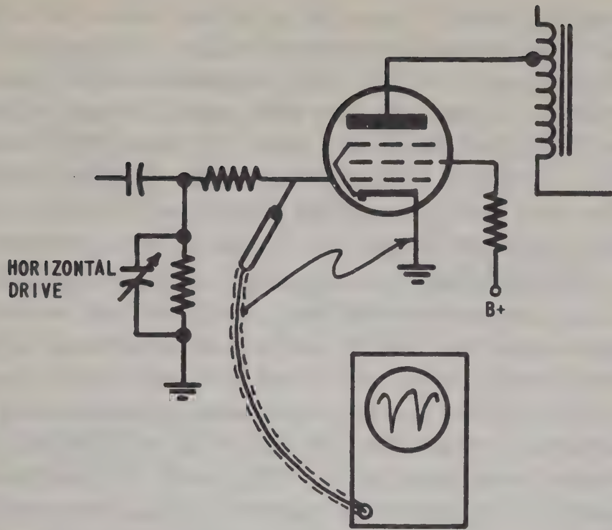

Fig. 9-12. Method of checking for sufficient horizontal drive.

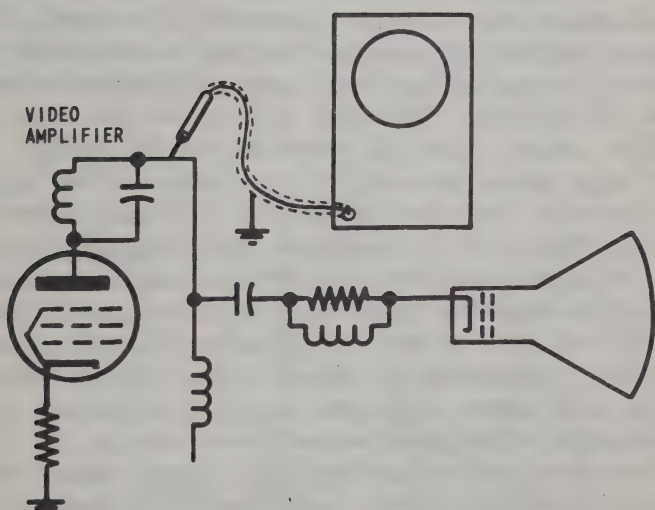

Fig. 9-13. Sync pulse signal tracing should begin at the output of the video amplifier.

the scope sync control set at the minimum value that will lock in about three complete waveform cycles on the screen. You should see a waveform that has a resemblance to a sawtooth. The sawtooth voltage will vary from one receiver to the next, but should be about 100 to 150 volts. If, instead of seeing the sawtooth, you get a horizontal line only, then the horizontal amplifier isn't getting its drive voltage and the trouble precedes the horizontal amplifier. If you do get a sawtooth having a sufficiently high voltage, the trouble (no high voltage) follows the horizontal amplifier. And, as long as you have the scope connected, (and if you have it calibrated) adjust the horizontal drive control (if the set has one) so that the peak-to-peak value of the sawtooth equals that recommended by the manufacturer. A sawtooth that doesn't have sufficient amplitude means insufficient drive. This could be due to a weak oscillator tube or incorrect adjustment of the horizontal drive control.

Picture Drift

The picture will drift (will not lock in) if the sync pulses do not get to the horizontal and vertical oscillators. To check, start at the output of the video amplifier, as shown in Fig. 9-13. Here you should see the composite video signal. Manufacturer's circuit diagrams will tell you what the peak voltage should be and will give you some idea of what the waveforms will look like. The next check should be at the sync amplifier output. Here the waveform will be cleaner, with mostly sync pulses present. If sync pulses do not appear, try a new sync separator tube. Keep the scope connected as shown in Fig. 9-14. If there is no sync here, but there are pulses at the plate of the video amplifier, check the components forming the connecting link between the two circuits. Finally, move the test probe to the input of the vertical and horizontal oscillators. If pulses do not appear at these points, but there is sync at the output of the sync separator-amplifier, check all connecting components between these circuits.

A scope can be used just like an ordinary signal tracer. Knowing the path of a signal, move along from stage to stage with the scope probe until you find a spot where the signal you are tracing disappears. It may not vanish completely, only partially, but in any event it will be enough to cause some

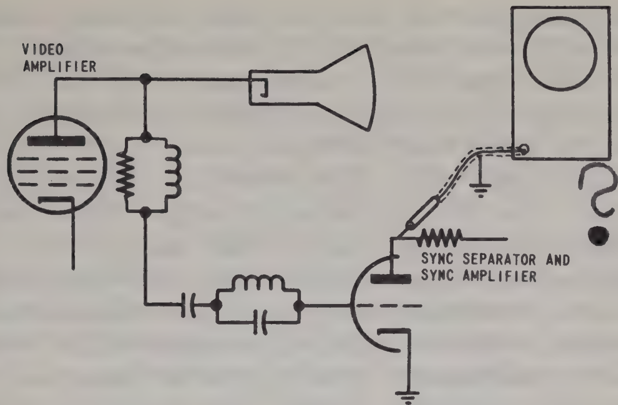

Fig. 9-14. Sync can be lost anywhere between the sync separator and video amplifier.

fault in set operation. Then, with the help of the VTVM you can trace down the troublesome component. In other words, use your scope to help you localize trouble, then use the VTVM to find the exact trouble spot. It is extremely helpful to use the manufacturer's circuit diagram, which not only tells you what voltages should be at various points, but also what the waveforms should look like and what the peak-to-peak values should be.

The basic idea here is really very simple, but it is also very effective. All it takes is some knowledge of the electronic theory involved—that is, if you want to repair a TV set you

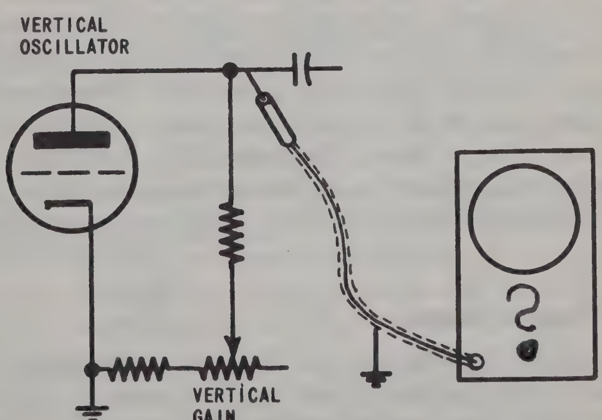

Fig. 9-15. The vertical oscillator can be checked by examining the plate waveform.

should at least know how it works. As an example, consider a TV set with just a horizontal line across the screen. Even with the vertical gain control at maximum, all you can do is to thicken the line a bit. Quite obviously the trouble is somewhere in the vertical sweep circuit. You certainly are getting high voltage, for without it you would not even get the horizontal line. Now you may have all sorts of other troubles, but the first step is to get some vertical sweep. In Fig. 9-15, the scope probe is connected to the plate of the vertical oscillator. A look at the manufacturer's diagram indicates that we should have a sawtooth waveform at this point and that it should be 75 volts peak-to-peak. If we get this waveform and it has a reasonable resemblance to that in the diagram, and if its amplitude is within kissing distance of 75 volts peak-to-peak, we can forget about the oscillator and move on to the amplifier. Transfer the probe tip to the plate of the vertical amplifier tube. Here, according to the manufacturer's literature, the waveform should be a trapezoid. At this point, though, you must be very careful. The trapezoidal voltage at the plate of the vertical amplifier can be in excess of a kilovolt. Instead of putting the test prod directly on the plate, just bring it close. If everything is working well, you'll get enough signal transfer to let you see the waveform on the face of the scope. ???

Here again we have been using the scope for two purposes: (1) To determine if the signal is present, and (2) To see what the signal looks like. If you get no sawtooth at the plate of the vertical oscillator, you need go no further. Resistance and voltage checks around the vertical oscillator will soon reveal the trouble. If you get the correct waveform, including amplitude, at the plate of the vertical oscillator, that is one more circuit you can forget about. If the oscillator waveform is OK, but you get nothing at the plate of the vertical amplifier, you've narrowed down the area of search, which was your whole objective.

Testing RF and IF Stages

Many service-type scopes have frequency limitations. For example, the frequencies of RF and IF television signals are usually too high to be reproduced directly. However, by using a demodulator probe to detect or rectify such signals before they are fed into the vertical terminals of the scope, you can

view the waveform of any modulating signal. Fig. 9-16 shows how this is done. But before we start, what is the complaint? It could be weak signal or no signal. Tune in a strong station or connect a suitable generator to the receiver input. Using the demodulator probe move from the plate of the last IF amplifier to the control grid of the same tube. Now move forward toward the front end. If you get the signal at the plate of the first IF but not at the grid of the second IF, it's obvious that you have trouble in the coupling IF transformer or that some component in the grid circuit of the following tube is killing the signal. If you get a signal when you check the final IF, then you have an indication you are heading in the wrong di-

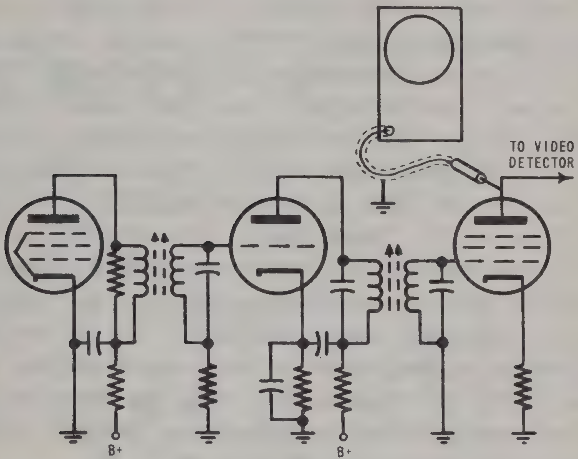

Fig. 9-16. An RF signal in stages preceding the second detector can be traced by using a demodulator probe.

rection and that you should consider the video detector and video amplifier as trouble sources.

Some service technicians consider the video load resistor as the receiver halfway point, and this is a good idea. Since the receiver crystal works as a demodulator, the demodulator probe isn't needed when checking across the diode load. If a signal is present across the load resistor (as shown on the scope screen), the trouble follows the video detector. If you get no signal across the diode load, look for trouble preceding this point. Thus, with the scope you can trace the signal all the way from the front end right on up to the picture tube input.

Now that you have the general idea of how to use the scope as an instrument for localizing troubles, get acquainted with the most common waveforms, their frequencies, and their amplitudes. However, using a scope is no substitute for common sense. If a visual examination of a TV set reveals a rectifier tube with a filament that doesn't glow and the complaint is no sound or picture, look no further. Just replace the tube. The point or points at which you are going to rest the needle point of a test probe will depend on the symptoms you notice. Thus, you first localize the trouble in your own mind, rejecting those circuits that could not possibly contribute to the cause of the trouble. You then use the scope to verify your suspicions and a VTVM to spot the actual culprit.

In Fig. 9-17 we have a whole series of waveforms of the type you can expect to see in a typical receiver; each is labeled as 1, 2, etc., and they will be referred to that way. Waveform 1 shows what you can expect to find across the video detector load or at the input to the first video amplifier. The zero-to-peak voltage is 3.5. Incidentally, in connection with these waveforms you will see two frequencies listed. One of these is the 60-Hz vertical sweep frequency and the other is the 15,750-Hz horizontal sweep frequency. Set the coarse frequency control on your scope to some sub-multiple, such as 30 Hz or 5,250 Hz respectively, with the sync control advanced just enough to lock in the pattern. (Input, of course, is to the vertical terminals of the scope.)

Waveform 2 shows the input to the cathode of the picture tube. If there is trouble in the TV set anywhere between the video detector and the input to the picture tube, you can now chase it down in the video amplifier. The input to the picture tube is the same signal that we have across the diode load, except that it has been amplified and, in some cases, inverted. At the picture tube input the video signal has increased to 55 volts peak-to-peak.

How can this information help us? Calibrate your scope and then move the test prod from diode load to picture tube input. You should have a gain of 15 to 20. If the gain is too low, replace the video amplifier tube and check again. In a test of this kind, and for all the other tests mentioned, the receiver should be tuned to an average station with the controls of the

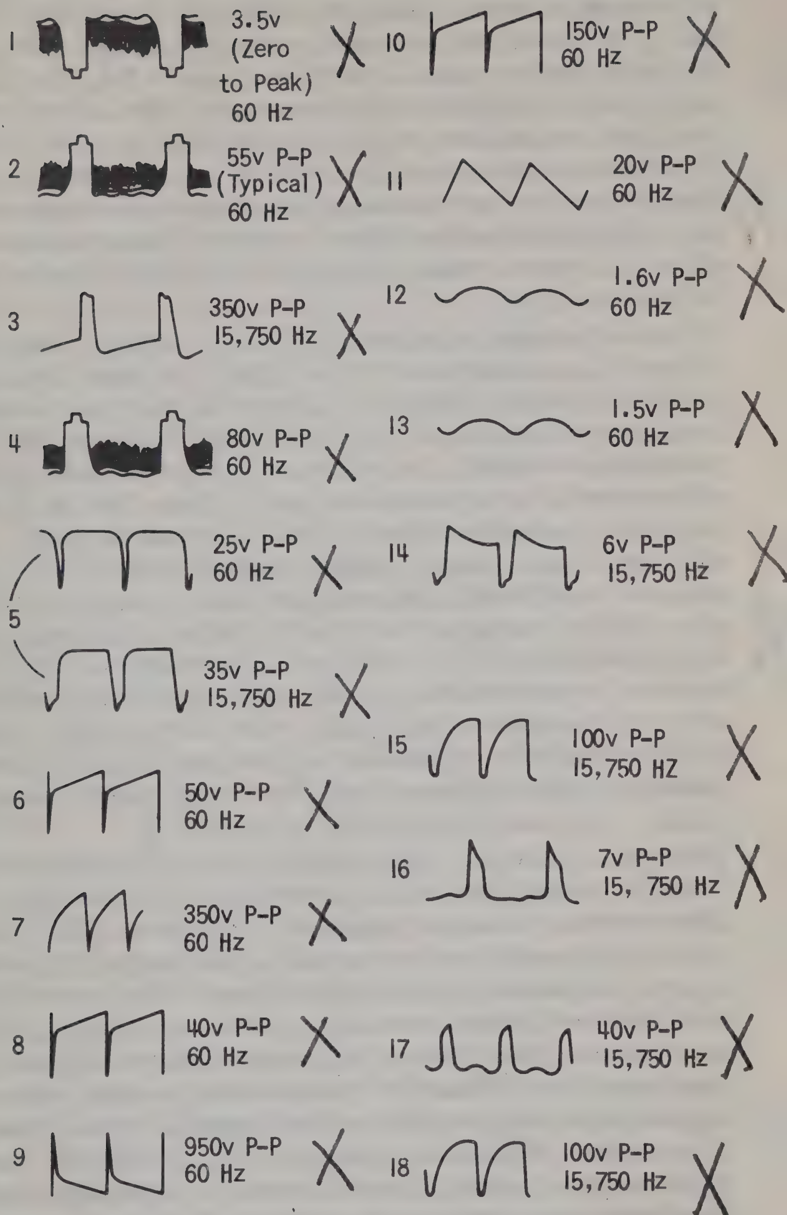

Fig. 9-17. Typical waveforms found in a TV receiver.

receiver adjusted as they would be normally. Waveform 3 represents the signal at the plate of the AGC keyer tube. This tube is pulsed at the horizontal sweep rate. The voltage is 350 volts peak-to-peak. Waveform 4 shows the signal input to the control grid of the sync separator. The voltage is 80 volts peak-to-peak and resembles waveform 2, as it should. If the problem is a picture that will not lock in, check at this point to see if you get the waveform shown in waveform 4. If not, follow the circuit back from the input to the sync separator, component by component, using the probe of the scope for signal tracing.

The two drawings in waveform 5 shows the voltage at the plate of the sync separator tube. At the plate of the sync separator there are vertical and horizontal pulses. Set your scope to 30 Hz and you should get a waveform, as indicated, with approximately 25 volts, peak-to-peak. Reset the coarse frequency control to 5,250 Hz and you will see the 15,750 Hz horizontal sync pulses, with about 35 volts peak-to-peak. You will recall the previous mention that the input to the sync separator was 80 volts peak-to-peak, and yet here is a plate pulse voltage having a maximum of 35 volts peak-to-peak. Anything wrong? On the contrary, everything is right. At the input to the separator there is the composite waveform, which, at this stage of the game, is like a lot of fat on a juicy slice of corned beef—just something to be trimmed away. Our sync separator works as a clipper; we're interested in the sync pulses. The rest of the signal isn't needed.

Waveform 6, at the plate of the vertical discharge tube, should be a trapezoid with a peak-to-peak value of about 50 volts. Failure to have a trapezoidal waveshape at this point means we are going to have vertical nonlinearity. Waveform 7 shows the pattern that should be present at the control grid of the vertical peak-to-peak value of 350 volts. Moving over to the control grid of the vertical output tube we will see the waveform shown in Fig. 9-17 (8). Here we have the trapezoid that will be amplified by the vertical amplifier tube. This is the waveform of the voltage across the vertical yoke coils. If now we move to the plate of the vertical output tube (waveform 9) the same trapezoidal waveform will appear, inverted, of course, and having an extremely high peak-to-peak amplitude. In the present instance it is 950 volts peak-to-peak, but it could be more. If the capacitor in the vertical input of your

scope is rated at only 600 WVDC you'll have a popped capacitor if you try to make a direct measurement at the plate of this tube. Do it indirectly by bringing the probe tip close, but not touching. Waveform 10 shows the trapezoid that will appear across the vertical coils in the yoke. You can check this by touching one of the resistors (each vertical coil is shunted by a resistor of about 5K) with the tip of the test probe.

The trend in low-cost TV sets is toward a half-wave, transformerless supply. You'll find either silicon or selenium rectifiers used. Waveform 11 shows the output at the junction of the rectifier (the rectifier cathode) and the first filter capacitor. What we see here is the ripple voltage. In this case it is 20 volts peak-to-peak at a frequency of 60 Hz. Naturally, the smaller the ripple voltage the better the filtering action, but if there is no ripple at all, chances are you have either no AC input to the rectifier anode, or else the rectifier has ceased working. Waveform 12 appears across the output filter. The peak-to-peak voltage has dropped to 1.6. If, however, the ripple voltage is much higher than this, start looking around for a new filter capacitor. Sometimes a power supply will have two separate filter sections, but both connected to the same rectifier. This is a way of avoiding the complications of a voltage divider across the output of a single filter. Waveform 13 is the ripple voltage at the output of a second filter and, as you can see, it is the same as the ripple voltage in waveform 12. This is perfectly normal and to be expected.

Horizontal tearing can be caused by some difficulty in the horizontal AFC circuit. If the picture cannot be locked in horizontally, and if the passage of horizontal sync pulses is OK up to the output of the sync separator, there may be some difficulty in the AFC circuit. Waveform 14 shows the voltage present at the junction of a pair of horizontal, dual selenium rectifiers, placed back to back. The frequency is 15,750 Hz and about 6 volts peak-to-peak. Absence of the waveform or an incorrect waveform (wrong waveshape) is your clue to start hunting around in the AFC circuit. Waveform 15 is the voltage at the control grid of the horizontal output tube. This voltage, 100 volts peak-to-peak, is used to pulse the tube. Absence of this signal driving voltage means less bias on the tube. Excess current through the horizontal tube can result in a burned out flyback, unless the flyback is fused, which is

not always the case. In some cases the horizontal output tube has a cathode resistor. This supplies some measure of protection since the increased current through the tube raises the bias developed by the cathode resistor. However, the horizontal output tube isn't always so provided. Loss of pulse voltage on the control grid of the horizontal tube, aside from the nasty things that will happen to the horizontal output tube and flyback, means loss of high voltage, and this in turn means no raster and, of course, no picture. If the symptom is no picture a quick check with your scope at the horizontal oscillator and at the horizontal output tube with your scope will soon localize the trouble. Naturally, an open fuse in the horizontal output is a clue—but not always. If the fuse opens, replace it and run a scope check on the horizontal sweep circuit just to make sure. Don't just replace the fuse and hope for the best.

Waveform 16 is found at the cathode pin of the horizontal oscillator. Waveforms 17 and 18 are at the plate pins of the oscillator, a multivibrator. These waveforms represent some of the principle waveforms to be found in a TV set. It is a good idea to become acquainted with their general shape and location.

Servicing Color TV

You will note that, aside from an occasional reference to an RF signal generator, the only equipment mentioned in this book are the three pieces of test apparatus we started with—the VOM, the VTVM, and the scope. But this is not to imply that these three are all the test equipment you should have. A sweep and marker generator is helpful. So are resistor and capacitor substitution boxes. And so is an audio generator, and an RF signal generator. But you can make do with the three we started with. Therefore, you shouldn't shy away from servicing color TV just because you don't have a color bar generator. It does make service work easker, but you can repair a color TV set with nothing more than a VOM, VTVM, and scope. A color TV set is not a black-and-white set with some sort of adapter added. But by the same token, a color TV set is not a new and completely radical departure from black-and-white either. Thus, you can service certain portions of the color set just as you would a black-and-white re-

ceiver. Now, here are some color problems and the techniques to locate them.

No Color

What do we mean when we say "no color"? This means a complete loss of all color, not just a loss of red, or blue, or green. If we have a complete loss of color we can eliminate the color detectors and the color amplifiers and the picture tube as the trouble source. The color detectors receive the color signal from the chroma bandpass amplifier, as shown in the block diagram in Fig. 9-18. We can check at the output of the chroma bandpass amplifier to see if the color signals have reached this point. During the time a black-and-white only signal is being received, the chroma bandpass amp-

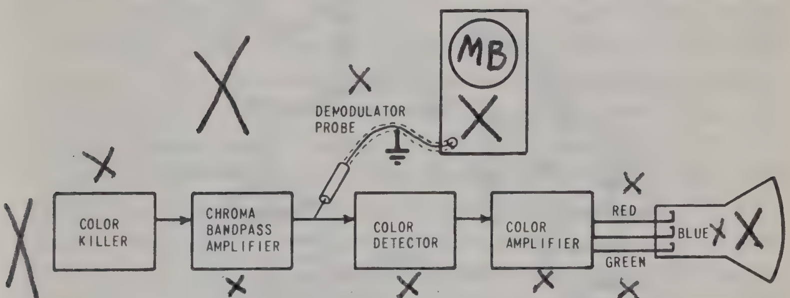

Fig. 9-18. Points to check for loss of color.

lifier is driven into cutoff by a heavy negative bias supplied by the color killer to the grid of the chroma bandpass amplifier. Connect the demodulator probe as shown, then if you fail to see the chroma waveform, remove the color killer tube from its socket. If the waveform appears on the scope, you at least know the trouble precedes the chroma bandpass amplifier. The trouble could possibly be in the chroma reference oscillator, the chroma sync phase detector, the color killer, or the burst amplifier. The trouble could be due to a defective tube, so try substituting these: the chroma bandpass amplifier (if you get no waveform when testing with the demodulator probe at the plate of the tube), the color killer, the chroma reference oscillator (3.58-MHz oscillator), and the phase detector.

If you're not getting a black-and-white picture, the trouble could also be a defective tube anywhere from the front end, through the video IFs and video amplifier. You can check the

3.58-MHz crystal chroma reference oscillator by measuring its bias voltage with the VTVM. The bias should be above -3 volts, preferably about -5 or -6 volts. If the voltage is zero or low, replace the tube; if that doesn't help, try a new crystal.

Weak Color

If the colors are weak, don't start worrying about a picture tube—at least not yet. First try substituting new bandpass and color killer tubes. Again, we'll assume the receiver is tuned to a channel for black-and-white reception. We do at

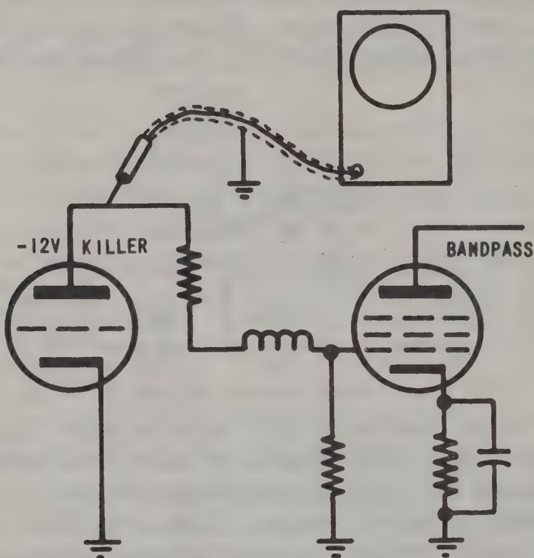

Fig. 9-19. Points to check in the color killer circuit.

least want to know if the front end, video IF and video amplifier tubes are doing their job. During reception of a black-and-white signal, the color killer passes on its negative bias, shown as -12 volts in Fig. 9-19, to the bandpass amplifier, effectively killing the color signal. During color reception this bias voltage is overcome by the waveform pulse shown in Fig. 9-20. This wave appears on the plate of the killer and is about 38 volts peak-to-peak. If the symptom is weak color, it may be that this voltage is not enough to overcome the bias.

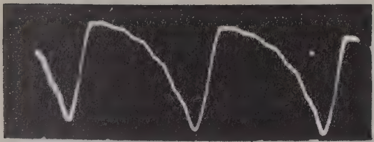

Fig. 9-20. Waveform at the plate of the color killer.

As a result enough negative bias is getting through to the bandpass amplifier to make it work in a weak fashion. A scope check at the plate of the color killer will tell you if this is so.

No Color Sync

Tube substitution is the first order of business if colors on the screen keep changing. Replace the reactance control tube, the phase detector, the 3.58-MHz oscillator tube, and the burst amplifier tube. Use your scope to check the waveform at the plate of the 3.58-MHz oscillator. Locate the phase detector, which has a pair of equal value resistors connected across the tube. These resistors will range from about 470K to as much as 1 meg. Ground the center point of these two resistors. (You will find a wire leading from this center point to the control grid of the reactance control tube.) This will kill the input signal to the reactance control tube. If the color picture still remains out of sync with this ground connection attached, look for trouble in either the reactance control tube circuit or in the 3.58-MHz oscillator.

Color in Black-and-White Picture

Check the color killer using the method described previously. If the color killer is working properly, check the phase detector and the 3.58-MHz oscillator.

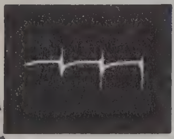

Fig. 9-21. Waveform at the plate of the burst amplifier.

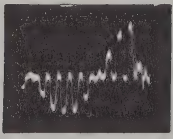

Fig. 9-22. Waveform at the red input to the picture tube.

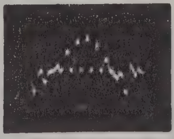

Fig. 9-23. Waveform at the blue input to the picture tube.

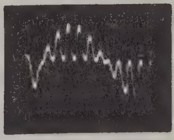

Fig. 9-24. Waveform at the green input to the picture tube.

Table 9-1. Color TV Troubleshooting Chart.

The Trouble	The Cure
No color or weak color.	Check to make sure black-and-white picture is OK. If yes, this eliminates front end, video IF and video amplifier as the trouble source.
	Measure the bias of the 3.58-MHz oscillator, using your VTVM set on a low-voltage DC scale. If you measure about 3 to 4 volts or more, oscillator is OK.
	Remove color killer tube or else ground its output. If color comes back again, check the color killer and the killer detector circuits. Make voltage and resistance checks in these circuits. Try new killer detector and color killer tubes.
	Color killer and killer detector may have a variable control for circuit adjustment. Follow manufacturer's instructions for proper setting of this control.
	Connect your scope to the plate of the burst amplifier. Fig. 9-21 shows the waveform. It should be about 25 volts peak-to-peak. If there is no burst signal on the plate, move the probe to the control grid of the same tube. In checking the circuit you will find that you will be able to trace back to the plate of the first video amplifier. Do this if you cannot see (on your scope) the burst signal on the control grid of the burst amplifier.
	The circuits to check in case of no color or weak color (with monochrome OK) are the bandpass amplifier, burst amplifier, phase detector, reactance circuit, 3.58-MHz oscillator, killer detector, and color killer.
No color on some channels	The trouble is up in the front end. Try substituting new front-end tubes. Sometimes due to improper setting of the fine tuning control.

Colors run. The picture is steady but there is no color sync.	Look for trouble in the phase detector, the reactance control circuit, and the 3.58-MHz oscillator. Measure oscillator bias voltage with a VTVM. If bias is OK, voltage and resistance check reactance control and phase detector circuits.
Red is missing or weak.	The trouble can be in the color CRT, the X demodulator, or the R-Y color difference amplifier. Use the scope to trace the signal, starting at the "red" input to the picture tube. Check back as far as the X demodulator. Fig. 9-22 will give you an idea of the waveform. It should be about 200 volts, peak-to-peak.
Blue is missing or weak.	The trouble can be in the color CRT, the Z demodulator, or the B-Y color difference amplifier. Check back from the "blue" input to the picture tube as far back as the Z demodulator. The waveform should resemble that in Fig. 9-23. It should be about 220 volts, peak-to-peak.
Green is weak or missing. Blue and red are present and are OK.	The trouble could be a defective picture tube, or in the G-Y color difference amplifier. Check back, with your scope, from the green input to the picture tube to the input of the G-Y color difference amplifier. Fig. 9-24 shows the approximate appearance of the waveform at the input to the picture tube. The voltage will be about 150 volts, peak-to-peak.
Wrong colors. Sync OK. Colors do not run.	Rotate the tint control and see if you can restore the flesh tones to individuals being telecast. If tint control cannot restore tones, try a new 3.58-MHz oscillator tube. Try a new 3.58- MHz crystal. The oscillator transformer may be severely misaligned. Resistance and voltage check components in the oscillator circuit.
Hum bar in color picture.	If hum bar appears in black-and-white picture, trouble can be due to heater-to-cathode leakage in some tube or poor filtering in the low-voltage power supply. If hum bars appear only in the color picture, try replacing the bandpass amplifier tube.

Index

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RANGES :

DC Voltages	:	0-0. 6-3-15-60-300-600-1200-3000 (30, 000 Ohms/V)
AC Voltages	:	0-6-30-120-600-1200 (15, 000 Ohms/V)
DC Current	:	0-0.03-6-60-600MA
Resistance	:	0-10K-1M-10M-100M (30Ω-3K-30K-300K at center scale)
Decibels	:	-20 to +46db
Batteries	:	1-1½V (Stock#23-468), 1-15V (Stock#23-509)

OPERATION

DC VOLTAGES — Up to 300 Volts :

* Insert the RED test lead into the + jack (lower right) and the BLACK lead into the jack (lower left).
* Select the range by turning the center knob.
* To measure, connect the test leads across the load or the sourse under test. Observe the proper polarities of the test leads.
* Read the voltage on the appropriate scale of the dial plate.

DC VOLTAGES — Over 300 Volts :

* Set the selector to 300V DC position.
* Insert the RED test lead into the 600, 1200 or 3000 Volts jack as repuired.
* Connect the test prods across the circuit under test and read scale. CAUTION ! High voltage circuits, both DC and AC, are very dangerous and should not be treated lightly. Take utmost care when making tests of voltages and currents in these circuits.

AC VOLTAGES :

* The AC voltages, up to 1200V, are measured with the test leads in the lower + and — jacks.
* Select the range by turning the selector to the ACV side.
* To measure, connect the test prods across the terminals under test. The polarities of the leads are not important.

DC CURRENT :

* Current measurements are made by connecting the tester in series with the circuit under test. Before measuring the tester in the circuit. make certain that the proper polarities are obserbed.
* Set the selector to 600MA and work down to lower ranges to obtain satisfactory readings.
* Take extreme care when measuring current, especilly the 30u A range to prevent meter burn outs.
* Check carefully to see that you are measuring current NOT voltage !

RESISTANCE :

* Insert the test leads into the + and — jack as previously noted, and turn the selector to the desired range.

SHORTING TEST :

* Before making measurements, always check the ZERO ohms setting, which is the full pointer deflection to the right, by shorting the test leads. Adjust the pointer to "0 Ω" on the ohms scale by turning the OHM ADJ knob (left center) on the panel.
* To measure, connect the test leads across the resistance device under test and read Ω on the scale. Apply the proper multiplier.
* In measuring the resistance of components which are mounted or wired in the circuits, precautions must be taken. The power source must be turned to OFF — in other words, the set must be "dead." One terminal of the component must be disconnected from the rest of the circuit. These precautions are necessary for (1) safety and (2) to prevent other resistors from affecting the measurement.
* Replace the internal batteries the "SHORTING TEST" fails to bring the pointer to "0" on the ohms scale.

DECIBELS :

* The lowermost scale is calibrated in DECIBELS for 0 DB=1 milliwattt (0. 774 V) in a 600 ohm line for the 6V AC range. Higher levels can be measured by increasing the voltage range and adding the appropriate number of DECIBELS (refer to table on the lower right of the scale plate).
* For impedance other than 600 ohms, the tester may be used for comparative measurements on a DECIBELS basis, using the same scale and ranges.
* Use the "OUTPUT" jack when measuring audio voltages across the primary of the audio output transformers, or other components Where DC voltages are present. An isolating condenser is connected internally in the tester circuit.

THE MODEL 22-049 MULTITESTER WILL BE FOUND TO BE THE MOST USEFUL INSTRUMENT IN THE LABORATORY, PLANT, SERVICE SHOP, ETC., AND SHOULD BE HANDLED AND USED WITH GREAT CARE.

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